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A survey of selected plant communities in the vicinity of Churchill, Manitoba.

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ABSTRACT

A survey of eight plant communities was conducted near Churchill, Manitoba (58° 45' N 95° 04' W) between August 21 and September 4, 1981. The formation processes of successive communities beginning at the sea shore and progressing inland are discussed. The community types include a rock-lichen association, salt marshes, beach ridges with a tundra-heath vegetative composition, spruce-lichen woodlands, palsa bogs, and peat plateaux. Abiotic and biotic factors influencing plant growth and plant adaptations to these factors in the arctic and subarctic are also emphasized. The role of permafrost and insulative peat layers in maintaining the periglacial structures is of foremost importance.

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FOREWORD

The material for this report was collected as a requirement for the undergraduate course Subarctic Plant Ecology at McMaster University, Hamilton, Ontario. Instruction consisted of two weeks (August 21, 1981 to September 4, 1981) of field exercises in the vicinity of Churchill, Manitoba with the main course requirement being a paper on the plant ecology observed.

The information contained herewithin is not hard scientific experimentation and analysis but an overview of the development of vegetation types in the Churchill area.

Specimens collected during the study are available in the Wildlife Branch Herbarium.

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INTRODUCTION

The forest-tundra is the transition zone between the subarctic "Taiga" and the arctic "Tundra". It is an intermingling of boreal and arctic communities. The northern limit of the treeline roughly coincides with the climatic frontal zone existing between arctic air masses and southern air masses in summer (Larsen 1980). The forest-tundra ecotone was created by the influence of latitudinal fluctuations of the front on the vegetation since the last deglaciation.

Churchill is unique in that it possesses forest-tundra communities similar to those found inland as well as communities under maritime influence.

Much descriptive research has been done in northern Manitoba (Ritchie 1959, 1960a, 1960b, 1960c, 1962) and particularly the Churchill area (Ritchie 1956, 1957, 1960b). Vegetative community types and permafrost structures have been described (Brown 1968, 1977, Sjors 1959) and climatological influences measured (Brown Beckel 1957, Larsen 1971). Little quantitative vegetation data can be found for Churchill although many such studies have been initiated in the Northwest Territories, Keewatin District, the Yukon, Alaska and northwest Manitoba. The lack of information may be related to the non-economic importance of the forest-tundra in Manitoba in the past.

The increased human activity in arctic and subarctic areas in recent years has prompted concern for the long term well being of the ecosystem. The vegetation is the primary producer in the food chain as well as providing cover and nesting material for a variety of faunal species.

The identification of plant communities and related landforms, not always immediately distinguishable, may serve as baseline data and environmental indicators for future studies on the effects of human disturbances. The increasing tourist trade at Churchill is providing additional vehicular

traffic and activity which may be detrimental to the landscape. It is necessary to identify areas of concern before the scales are tipped too far and recovery of the land is impossible. This publication will hopefully aid in providing basic information on the development of forest-tundra vegetation communities.

The objectives of this study were to identify, sample and describe as many landforms and plant communities as possible and relate these features to ecological and environmental factors within the Churchill area. The study took place over a two-week period beginning August 22, 1981 and ending September 4, 1981.

STUDY AREA

Location

A study of forest-tundra and coastal marine landforms and plant communities was initiated at several sites within a 276 km^2 area in the vicinity of Churchill, Manitoba (58^{o} 45'N, 95^{o} 04'W)(Fig. 1). The area is in the Hudson Bay Lowlands on the west coast of Hudson Bay. The townsite is located at the mouth of the Churchill River on the east bank. Various habitat types were observed on both sides of the river, along the coast and at inland locations. These included salt marshes, rock ridges, peat bogs and forest stands.

The Churchill region occurs on the northern edge of the treeline, possessing a forest-tundra type of vegetation described as a transition between the taiga and tundra (Rowe 1972). The general physiognomy of the area is a vast tundra resembling a grassland, scattered with small ponds and clumps of stunted black and white spruce (Picea mariana and P. glauca), with tamarack (Larix laricina) found in localized distributions (Rowe 1972, Shelford and Twomey 1941)(Fig. 2). The tundra is composed of muskeg (Terasmae 1977) or various types of peatland communities. These include fens, dominated by Carex spp., bogs with mosses, ericaceous shrubs, lichens and trees. Several combinations, variations and gradations of the two communities are widespread. Beach ridges, covered with a variety of upland species of herbaceous plants, ericaceous shrubs, mosses, lichens and spruce are common (James 1977, Tarnocai 1974).

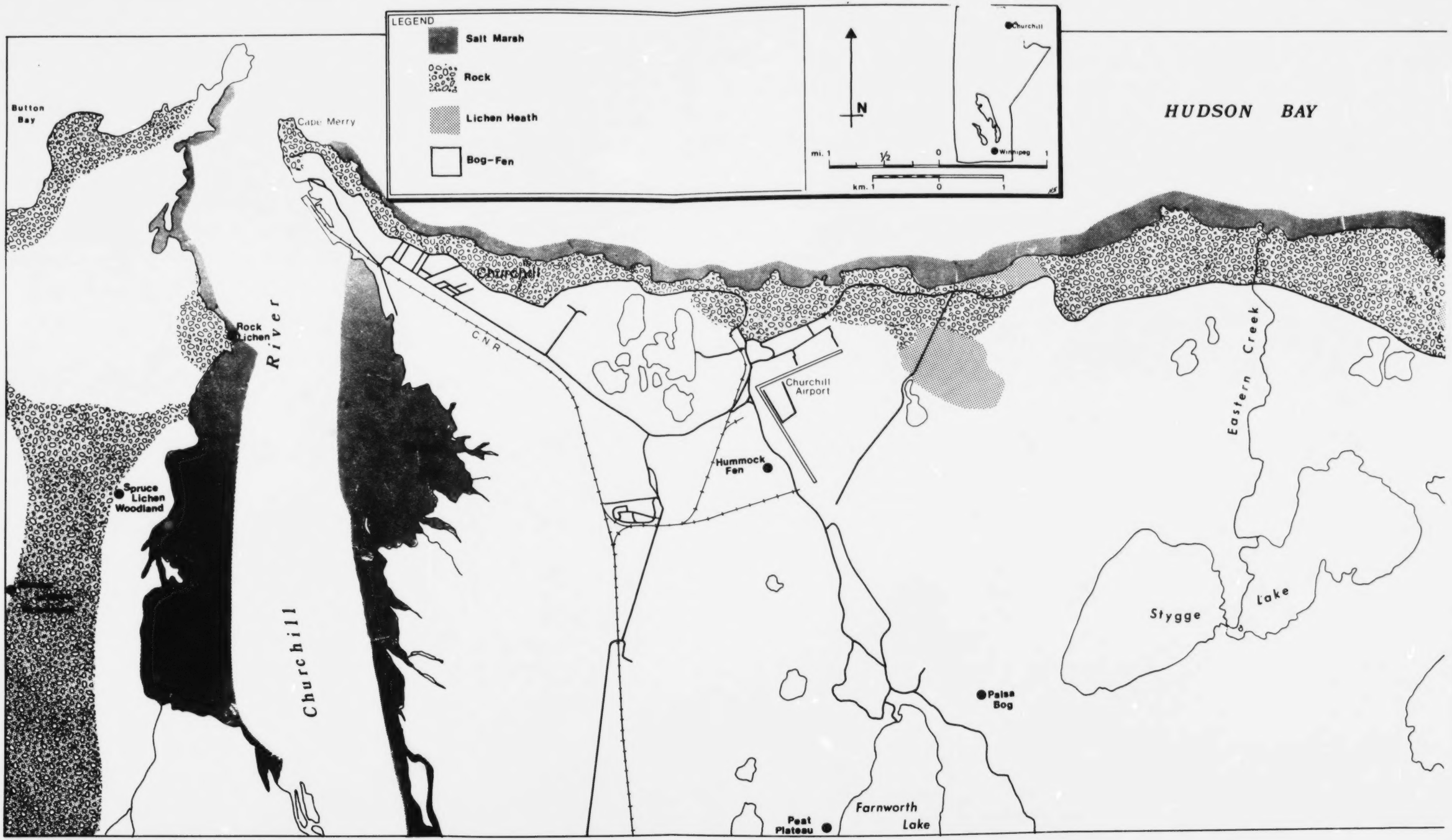


Figure 1: Habitat map of Churchill study area.

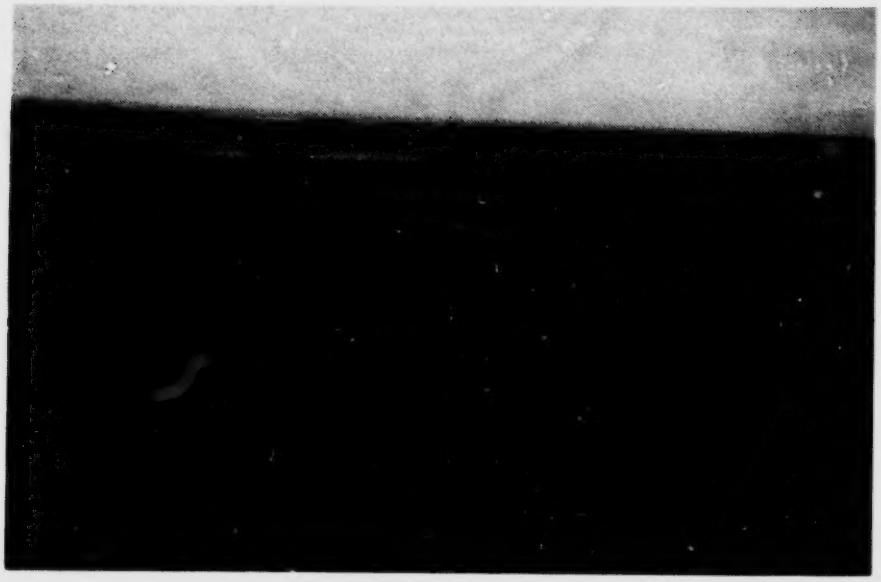


Figure 2: General appearance of the study area; numerous lakes and bogs are interspersed with beach ridges, treed palsas, peat plateaux and string bogs.

Geological History

The geology of the Churchill area is represented by localized deposits of Precambrian and Proterozoic granites, gneisses and folded strata of quartzite, dolomite, greywake and argillite with some volcanic deposits. Flat-lying sediments of Ordovician limestone are widespread above the glacial till layer and under the marine deposits of silt, clay and gravel (Hora 1977, Whitmore and Liberty 1968).

All of Manitoba was covered by the Wisconsin-Laurentide ice sheet 18,000 years ago (Lee 1968). As the climate warmed and glacial melt was initiated in the south 10,000 years ago, the glacial margins withdrew and large lakes were impounded, one of these being Glacial Lake Agassiz. As melting occurred in the northern part of the glaciated region 8,000 years ago, the ice

sheet split into remnant pieces allowing invasion of salt water through Hudson Strait (Lee 1968). These waters formed the Tyrell Sea; Hudson Bay is a relict of this inland sea. The maximum boundaries of the salt water were 250 to 300 km inland from Churchill, as evidenced by marine deposits.

Isostatic uplift or post-glacial rebound occurred after the ice sheet melted and the great weight which deformed the earth's crust was removed. The result of this continuing process are the numerous beach ridges paralleling the coast. It is thought that the ridges rise at a rate of approximately 1 m every 100 years (Hora 1977, Terasmae 1977, Cheney and Brown Beckel 1955). The uplift of the land and the recession of the sea boundary resulted in a continuing deposition of inwashed silt, sand, gravel and boulders forming beach ridges (Lee 1968). Raised beach ridges of the Tyrell Sea are evident today appearing 123 to 185 m a.s.l. (Lee 1968).

Topography and Soils

The tundra appears as a featureless plain, generally poorly drained but it can be locally well-drained. Permafrost is present at varying depths which in conjunction with the severe climate strongly influences the landscape (Hora 1977). Slight relief is afforded by numerous beach ridges and two conspicuous Churchill quartzite ridges along the coast forming banks at the mouth of the Churchill River (Fig. 1)(Hora 1977, Cheney and Brown Beckel 1955).

Generally an organic layer of varying thickness has been generated overtop the marine and glaciolacustrine deposits and glacial till. Newly formed beach ridges exhibit sand and silts on their surfaces. Many small ponds and thermokarst lakes dot the landscape (Cheney and Brown Beckel 1955).

Climate

The climate of Churchill is a transition between arctic and sub-arctic (Cheney and Brown Beckel 1955) with an annual average temperature of -8°C (Anon. 1962). The warmest month is July and the coldest January, average temperatures range between 14°C and -28°C respectively (Anon. 1962). Extreme maximum and minimum are 36°C and -45°C. The average number of frost free days with an effective growing season of only 95 days (James 1977).

An average of 23.0 cm of precipitation falls throughout the year, 44% of this occurs as snow, the remainder in the form of rain, sleet and fog. Snow cover thickness averages 140 cm (Anon. 1962).

Wind is an important climatic factor in the vicinity of Churchill. The average wind speed is 22.5 k.p.h., prevailing from the north-northwest (Anon. 1962), but speeds as high as 160 k.p.h. have been recorded (Thompson 1968).

VEGETATION AND THE ENVIRONMENT

In combination with climate, three major environmental factors influence the distribution, growth form and productivity of subarctic and arctic species. Peat, snow and permafrost have profound environmental effects associated with their properties.

Peat

Peat is the parent material formed by the accumulation of organic remains (Walmsley 1977). The type of peat laid down depends on the originating vegetative material and degree of decomposition (Walmsley 1977, McFarlane 1969). In general, amorphous-granular peats, derived from slightly decomposed herbaceous species and blue-green algae are found in the fens and at the bottom of ponds. Fine-fibrous peats, derived from mosses, are found in the bogs, peat plateaux, palsas and forests of the arctic and subarctic (McFarlane) 1969). The quantitative properties of specific samples varies greatly with the degree of decomposition, botanical origin and mineral contaminants. However, the overall influence in the subarctic and arctic is similar.

Peat has a great capacity for water absorption (Walmsely 1977, Brown 1970, McFarlane 1969). This property is important because it allows peat to act as a water reservoir for vegetation on highly exposed sites and over well-drained substrates such as sand (Rouse and Kershaw 1973); fibrous peats are the most successful (McFarlane 1969). The cool anaerobic environment created by the saturated material further retards decomposition of vegetative litter and allows for fairly rapid accumulation of additional peat (Reader 1978).

On drying, peat shrinks, becoming crusty, firmer and upon cracking exposing the underlying substrate. Decomposition of underlying peat is accelerated by exposure to an aerobic environment and is subject to erosion

(McFarlane 1969). This property is particularly important in the maintenance of periglacial structures such as palsas, peat plateaux and hummocks.

Permeability varies, depending upon the amount of mineral water, degree of consolidation and extent of decomposition. Horizontal permeability, especially in fibrous peat, is much greater than in the vertical direction (McFarlane 1969). This has far-reaching consequences on subsurface moisture, nutrient runoff and the formation and maintenance of periglacial structures. This limits the amount of moisture drawn to the surface and lost to evaporation when free water is in short supply.

Specific gravity is usually greater than 1 but can vary drastically with the presence of entrapped gases, especially methane, which are products of anaerobic decomposition (McFarlane 1969). If the gas content is great enough it may provide buoyancy for the peat mat above the water table, this is illustrated by floating mats of Carex spp. and blue-green algae around pond and lake shores. Marsh gas, or methane, is released from these mats when disturbed, providing the characteristic marsh odour.

The thermal characteristics of peat are of greatest importance to vegetation in the arctic and subarctic permafrost zones. In the environment there is a heat flux from warm to cool. The status of peat deposits over the landscape influences the rate of flux between the air and substrate. Peat acts as a heat sink with varying rates of heat conduction, depending on condition.

Dry peat has the lowest coefficient of heat conduction compared to saturated and frozen peats (Walmsley 1977, McFarlane 1969). In summer, saturated peat deposits above the water level dry due to evaporation. A large amount of heat energy is required; therefore, energy which would otherwise be used to melt the permafrost is lost and the underlying soil remains relatively

cool. There is a slow thaw of permafrost. This situation parallels the conditions which maintain peat plateau and palsas.

Saturated peat has three times the thermal conductivity of dry peat (Pruitt 1978). In summer, heat from the sun is trapped within the wet peat, penetrating deep into the substrate and melting the permafrost. A wide active layer is thus created as can be found in fens.

As winter approaches, less evaporation takes place, the peat layer becomes saturated and freezes (McFarlane 1969). Thermal conductivity of frozen peat is much higher than that of unfrozen peat (Pruitt 1978). There is a heat flux of the stored energy from the warm ground to the cold atmosphere and there is less resistance to cooling by the underlying ground and peat (Walmsley 1977).

The heat transferred from the ground to the atmosphere in winter is greater than that transferred from the atmosphere to the ground in summer. The net result is a negative heat balance and the maintenance of permafrost year-round (Pruitt 1978, Brown 1970). The seasonal heat flux, however, is moderated by vegetation, soil moisture, and particularly snow cover.

Snow

Snow commonly covers the landscape for six to ten months of the year (Slaughter and Cook 1971). The topography and vegetation density, growth form and distribution determine relative accumulations. Snow may be regarded as the ecotone between the macro and micro-environment (Pruitt 1978). On flat, open, wind-blown tundra, hard snow may collect to a thickness of 30-45 cm during the winter. In forested areas, where there is protection from the wind, softer snow collects, often exceeding depths of 1.3 to 1.5 m. In the lee of ridges or on the edge of forested areas, soft or hard drifts occur, they can be 1.5 m or greater in depth. The hardness depends on the degree of exposure to winds (Brown Beckel 1957).

The role of snow as an insulator varies according to its hardness, moisture content and thickness (Brown Beckel 1957). Steep temperature gradients are set up for extended periods of time (Pruitt 1978). Highest temperatures occur at the soil surface (Slaughter and Cook 1974). The zone between the snow surface and 7.6 cm below the surface fluctuates with the ambient temperature while the zone below 15 or 20 cm is relatively free of fluctuations and provides a stable environment (Pruitt 1978).

Soft snow is a better insulator than hard tundra snow (Brown Beckel 1957). Hard snow usually occurs in shallow accumulations. It has a high heat conductivity and low reflective ability. Densification of tundra snow by wind increases transmissivity to light and heat. For example, a two fold increase in density increases heat transmissivity four times (Pruitt 1978). Hard snow absorbs heat from the soil surface, allowing greater frost penetration and a harsher environment from underlying vegetation. The low albedo allows the snow to absorb more solar radiation and thus has temperature fluctuations comparable with ambient temperatures, creating an unstable environment for vegetation.

Soft snow, usually found in thick accumulations, is a better insulator because the numerous air spaces allow entrapment of warm air. Heat conduction is lower than in hard snow (Brown Beckel 1957); it allows the warmth to remain in the ground. A high albedo serves to moderate temperature (Brown Beckel 1957).

One problem associated with extended periods of snow lie is dessication (Slaughter and Cook 1974). Vapour transport is constantly occurring from the ground to the snow surface. In windy environments, it is increased. The longer the snow stays, the longer this type of dessication takes place. Blowing snow and ice crystals abrade exposed plant parts causing injury and

increased dessication. Collection of snow on tree limbs may also cause injury by breakage as well as providing insulation. Vegetation must be adapted to these restrictive situations.

The long period of snow cover, with a high albedo has a great impact on overall vegetation growth. Energy loss through direct reflection of one half or more of incoming solar radiation affects potential productivity of plant communities as well as thermal stability of the environment. During periods of melt the energy used in phase change from solid to liquid and vaporization is energy that is not available for other purposes (photosynthesis, warming of the soil, warming of the plants)(Slaughter and Cook 1974).

The accumulation of snow cover also regulates local drainage and water supply. The amount and timing of runoff greatly affects the formation of plant communities. Vegetation must be quick to utilize moisture when it is available. The quick spring melt imposes thermal stress upon the vegetation, exposing it to ambient fluctuations (Pruitt 1978). Vegetation growing in the subarctic and arctic with long periods of snow cover must be well-adapted to extreme dry and cold situations.

Permafrost

Permafrost is defined as a substratum below freezing for two or more years (Pruitt 1978). It can be loam, peat, sand, gravel or rock. Permafrost exerts many restrictions upon vegetative growth, edaphically and above the surface. Concrete ice is present at varying depths beneath the surface of all vegetated areas in the vicinity of Churchill. Its impervious texture is equivalent to bedrock, preventing the establishment of plants. The concrete ice is subject to solifluction and churning of the ground (Johnson 1963).

Root growth is restricted to the active layer, which varies in thickness depending on grain size of substrate, water supply, insulation, insolation,

and duration of summer temperatures. Thinnest active layers are found under thick dry peat deposits, such as bogs, palsas and peat plateau, where insulation is high. Wide active layers are found under fens where standing water, a poor insulator, allows the ice to melt. Sandy soils have a high heat coefficient, warming easily encouraging ice melt (Washburn 1980). In the active layer, permafrost maintains low temperatures in the root zone, restricting metabolic activity, impeding uptake of nutrients and growth (Johnson 1963).

Permafrost impedes drainage, restricting percolation of water into the ground and often impounding it, creating the numerous thermokarst lakes, ponds, and bogs. Most soils are supersaturated in spring and fall when precipitation is greatest. Permafrost helps to maintain this situation throughout the summer and fall (Brown 1963, Johnson 1963).

The supersaturated condition in association with the underlying permafrost leads to a great deal of frost action which results in surficial disturbances and displaced soil and vegetation (Bliss 1960, Johnson 1963). Differential expansion of saturated soils on freezing initiates structures such as hummocks and palsas as well as creating patterned ground. The creation of these structures produces several new environments for colonization. For example, a high centred polygon will create a dry exposed environment in the centre with more moist conditions around the periphery and a related species differentiation.

The melt of underlying permafrost creates thermokarst conditions and a constant creation of new topographic and microclimatic influences.

Congeliturbation or the churning of the ground in response to frost action alters the surface by projecting rocks throughout it. This is caused by successive freeze and refreeze cycles within the active layer in one year or over several years, shifting underlying objects. The resulting surficial

changes influence the microenvironment for vegetation colonization and continued growth (Washburn 1980, Johnson 1963).

Vegetation on the other hand, has an effect on the promotion and maintenance of permafrost. Vegetative cover determines the heat flux between air and soil (Daubenmire 1978, Billings and Mooney 1968, Brown 1963). Plants intercept solar radiation, reflect great amounts and thus keep the soil cool. Evapotranspiration removes a great deal of heat from the soil. Vegetation intercepts precipitation, limiting percolation to the roots, thus cooling the water before absorption. Roots impede runoff influencing the microclimate and keeping the warm summer precipitation to a localized area. Vegetation forms peat whose properties have previously been discussed. The effects can be seen when vegetation is removed. As permafrost melts, slumping occurs and structures collapse (Brown 1963, Bliss 1960).

Vegetation also insulates against frost action by limiting soil saturation levels and extreme heat fluxes. It insulates against melting in the summer and limits frost penetration in the winter.

The process of permafrost formation and maintenance is a circular process, factors interact with each other in such a way that linear relationship cannot be distinguished. Effects of permafrost on vegetation are reflected in the effects of vegetation on permafrost. This system will maintain itself as long as wholesale disturbances such as plowing and continuous vehicular traffic do not upset the balance by disrupting the surface cover.

Plant Adaptations

Some of the environmental influences of peat, snow and permafrost on vegetation have previously been discussed. In addition, factors severely limiting vegetative growth are temperature (Bliss 1960), drought and disturbance. The influences of the environment are expressed in adaptations of the plants.

The growth form and pattern of distribution is a product of the environment as well as having profound influence upon it (Daubenmire 1978, Billings and Mooney 1968, Brown 1963). The majority of arctic and subarctic plants are angiosperms, bryophytes and lichens. Most angiosperms are herbaceous perennials or prostrate shrubs. The herbaceous perennials have four general growth forms, cushion plants (Dryas integrifolia), rosette plants (Cerastium spp.), leafy stemmed (Arnica arctica) and grass form (Carex spp. and Elymus arenarius)(Pruitt 1978, Billings and Mooney 1968). The distribution of individual plants regulates the relative amounts of solar radiation reaching the substrate. For example, widely spaced rosette plants such as Cerastium spp. allows solar radiation to reach the soil surface raising the temperature and altering the moisture regime relative to the remainder of the area. Grasses and sedges which grow in aggregations produce a turf which cannot be penetrated by the sun, maintaining a relative constant temperature and moisture gradient (Billings and Mooney 1968). The low growth form of the majority of the species allows them to take advantage of the warmth at the soil-air interface (Daubenmire 1978, Billings and Mooney 1968, Bliss 1960). Strong pigmentation by red anthocyanin helps trap incoming solar radiation and aids the leaves in remaining warm and photosynthesizing. The pigmentation also allows many species (Arctostaphylos rubra, Vaccinium spp.) to trap the outgoing infrared radiation under snow banks and begin photosynthesis before the completion of spring melt (Savile 1972).

The presence of vegetative material adds to the effects of micro-topography, providing a barrier on which snow and sand will collect, in turn producing effects on the microclimate, in localized areas. These are increased insulation, moisture, abrasion and reflection. In addition there are phytomicroclimates found within the environment of the plants themselves

(Bliss 1960). From the tip of the leaves to the roots there are temperature and osmotic pressure gradients (Billings and Mooney 1968).

A large majority of subarctic and artic plants exhibit rapid shoot growth after and during spring melt. The energy and material required for this quick growth are supplied by carbohydrates and lipids from the previous season stored in roots, rhizomes and bulbs (Daubenmire 1978, Billings and Mooney 1968). Evergreens will drop their old, winter-damaged leaves and sprout new ones. Their carbohydrate supply is stored mostly in the stem and healthy leaves (Savile 1972). Primary production in the arctic and forest-tundra is limited primarily by light and temperature (Miller and Tiezen 1972, Bliss 1960). Tundra plants follow the pattern for maximum primary production under microenvironmental conditions. Where water is in good supply, leaves are steeply inclined and narrow, and leaf area indices are high, as in sedge meadows and fens. Where water is limiting, leaves are horizonatal and broader, and leaf indices allow photosynthesis to take place early and late in the growing season (Savile 1972). This allows them to utilize solar radiation to a maximum when it is most available.

Sexual reproduction is usually replaced by apomixis, vivipary of other forms of vegetative reproduction. Flowering and seed production do take place but are highly dependent on environmental conditions (Daubenmire 1978, Billings and Mooney 1968). In those plants that do flower, the flower buds are produced the previous year, and remain dormant until suitable conditions exist the following summer (Billings and Mooney 1968, Bliss 1960). Pollination is dependent upon insects and wind in a compressed time period of two to three weeks (Daubenmire 1978, Billings and Mooney 1968, Bliss 1960). Flowers are well-adapted for the attraction of insects, exhibiting bright blue, pink and purple flowers and providing a rich nector source (Saville 1972). Seed production is opportunistic and dependent upon temperature during the flowering

period and latter half of the growing season. Seeds can remain dormant or frozen for a number of years until suitable germinating conditions exist, the most important condition being suitable temperatures (Bliss 1960). Seed dispersal is mostly by wind. Some plants have fleshy nutlets and fruits that are eaten by animals and thus the seeds are transported (Savile 1972). Seedling establishment is rare, very slow and does not demonstrate the major colonizing strategy of arctic and forest-tundra plants (Billings and Mooney 1968).

Vascular plants have adapted their growth habits and leaf morphology to the environmental influences, cespitose forms being most successful (Bliss 1960). The tendency toward evergreen leaves in harsh drier environments allows conservation of materials for leaf production from year to year (Daubenmire 1978, Billings and Mooney 1968, Bliss 1960). Evergreen leaves also allow the plant to function during short periods of warmth at the beginning and end of winter (Daubenmire 1978). One disadvantage is the risk of freezing damage in exposed sites (Billings and Mooney 1968).

Arctic and subarctic plants have adapted for survival in extreme freezing temperatures by producing high concentrations of soluble carboyhydrates (Billings and Mooney 1968, Bliss 1960), and altering osmotic potential expelling free water, with the onset of winter (Daubenmire 1978, Bliss 1960). These two factors prevent freezing and bursting of tissues.

Many species, especially those of exposed, windy habitats, can withstand extremely low temperatures and dessication (Daubenmire 1978, Billings and Mooney 1968). Saxifraga spp. are good examples of these properties.

Wind affects plants in several ways. It decreases air temperature by mixing air and thus increasing evaporation as well as further cooling the soil and plant. It decreases the activity of pollinating insects (Daubenmire 1978, Bliss 1960). Wind causes much mechanical damage with the abrasion of ice, snow and salt spray and the rubbing and breaking of branches (Saville 1968).

Evergreen leaves combat some of these effects with firm waxy cuticles providing a barrier to evaporation and protection from abrasion (Bliss 1960). Hairs on the leaves increase the size of the boundary layers thus reducing evaporation (Bannister 1976). Low growth habit also allows the plants to be protected by snow cover (Daubenmire 1978) and microtopographical features.

For taller plants, which extend above the snow line, wind and snow shape their growth form. Krummholtz is a common sight in the subarctic where frequent strong winds gnarl growth (Ritchie 1957)(Fig. 3). The spruce trees of the subarctic often exhibit a candelabra effect where growth above the snowline is greatly damaged by exposure while branches below the snow are full and healthy (Fig. 3).

The species which have successfully established in the arctic and subarctic are those whose genetic plasticity have allowed for rapid adaptation to the harsh conditions.

In general, lichens and mosses are highly adapted to the extremes of the arctic and subarctic environment. They can withstand lower growing season temperatures than most vasculars (Kappen 1974). Soil moisture is not a constant requirement, surface moisture is sufficient for most species, especially lichens. They are able to withstand diurnal and seasonal temperature fluctuations and extremes (Billings and Mooney 1968).

Lichens and mosses can remain dormant for long periods of time when conditions are unfavourable. They are long lived; therefore the production of biomass each year is less urgent than in vascular plants (Kappen 1974). Lichens are further adapted as reproduction is accomplished largely by fragmentation. Little additional energy or biomass is needed to produce special reproductive structures.

Lichens and mosses have become successful in the arctic and subarctic because they are able to fill a niche in which vascular plants are unable to grow.

Figure 3: The typical growth form of subarctic trees, krummholtz induced on exposed limbs and the candelabra effect due to protection of snow cover.

PLANT COMMUNITIES

Coastal Rock-Lichen

Litholitic lichens are an exceptional group of organisms which can live off a minimal amount of nutrients supplied by leaching and weathering of bare rocks. The type of colonization, composition and structure of lichen aggregations is determined by chemical and physical properties of rock and by reaction to weathering (Magomeda 1979).

A Churchill quartzite ridge was studied in relation to its litholitic lichen population. The site sampled is part of a Churchill quartzite ridge (Hora 1977), commonly called the "whale back" running north and south along the peninsula between Button Bay and the Churchill River (Fig. 1). The sampling site forms the west bank of the river at Cockle's Point, opposite the port of Churchill (Fig. 1). The rock face sampled is oriented toward the east and tidal fluctuations bring water levels up to the base of the rock.

The species composition and distribution along the slope are a response to a number of abiotic and biotic factors. Substrate stability, texture, hardness, chemical structure and aspect are the major determinants of the community type which will colonize. Microtopography, heat balance, exposure, snow cover, distance from initial point of colonization and competition determine the species distribution within the community (Larson 1980, Armstrong 1978, Orwin 1972, Rejmanek 1971).

Churchill quartzite, a stable, hard, slow weathering, acidic rock (Ahti 1977) provides an environment for the establishment of a saxicolous lichen community. Aspect of the rock face studied was to the east, lying on the leeward side of prevailing northwest winds. Snow drifts over the top of the ridge and lies along the slope with the lowest elevations receiving the

greatest snow accumulations. The eastern aspect exposes the rock face to less intense morning sunlight.

As one climbs up the rock, the angle of incidence with the sun and heat balance changes (Bliss 1960). The base of the ridge receives the lowest intensity and shortest duration of sunlight, remaining relatively cool, as opposed to the summit. The latter receives the hottest sun and longest duration, resulting in the greatest diurnal fluctuations in temperature. Small perturbations of the surface influence the reflectivity and heat balance. It takes only a small microtopographic difference to have a significant effect on microclimate in the subarctic (Billings and Mooney 1968). Depressions provide more shade, thereby remain cooler, and evaporation is more restricted.

A flow of leached nutrients from the top to the bottom of the slope occurs but there are probably minimal differences along the smooth face of the rock. Some of the runoff collects in the depressions, enriching the environment by creating their peat and silt layers where vasculars, mosses and fruticose lichens can grow. The most common species found in these depressions are Arctostaphylos rubra, Salix spp., Alectoria nitidula and A. ochroleuca.

Exposure to winds and weather along the slope is dependent upon the microtopography. The depressions are the most protected with a moderated environment relative to the rest of the slope. The localized minor undulations are more exposed to the elements and the summit remains openly exposed with the drying winds creating a veritable desert.

Figure 4 illustrates a transect along the rock face showing the topography of the surface and the distribution of lichen species along this surface.

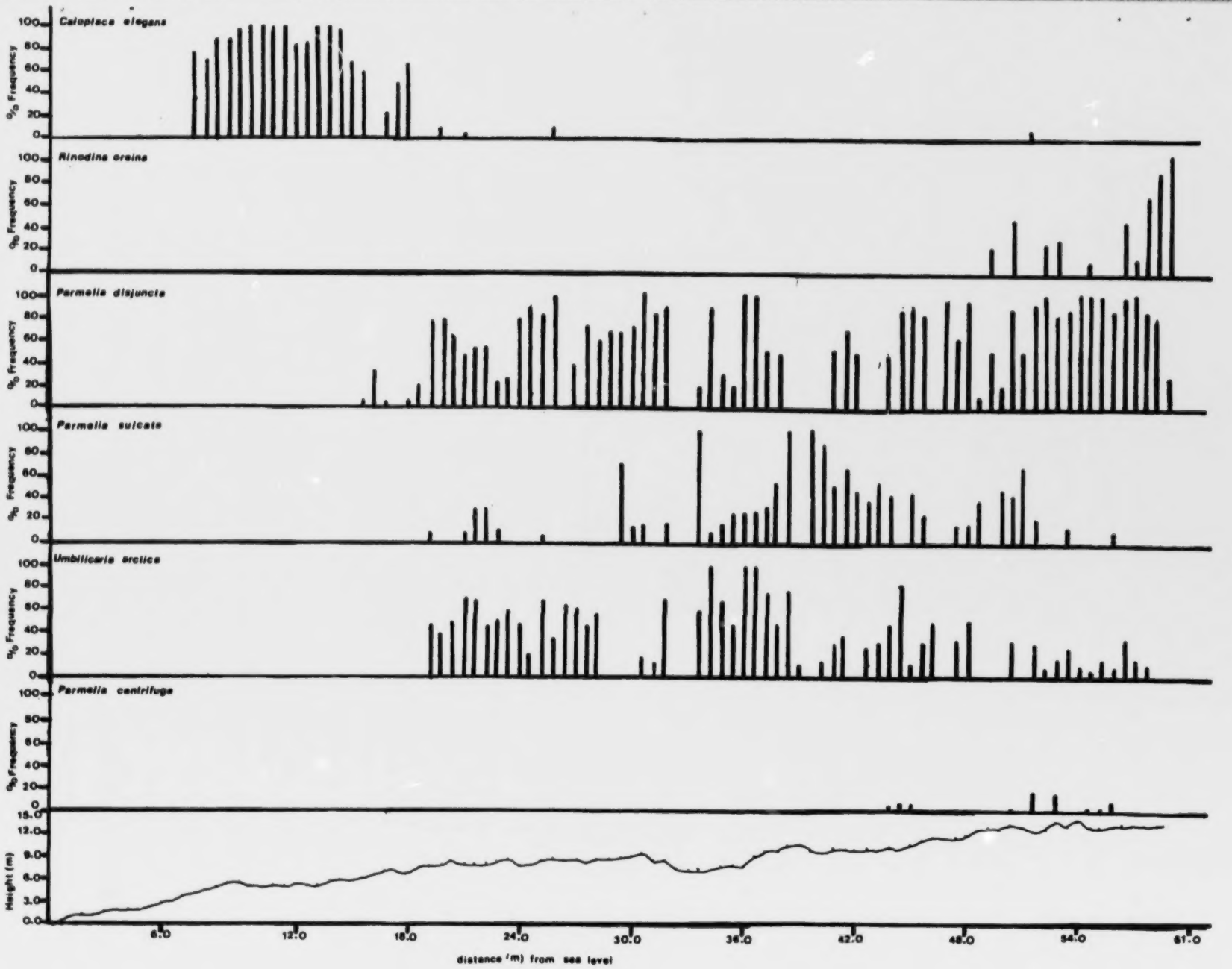


Figure 4: Profile of a rock-lichen community indicating species distributions along the transect.

The absence of lichens just above the high tide mark, as indicated on Figure 4, may be attributed to lack of tolerance of wave action, ice scouring and salt concentrations. The high tide water level comes to the base of the rock but in rough weather it is not uncommon for waves to be whipped up the side of the rock. Ice scouring scars are evidence of glacial activity and floes being shoved up onto the rock at spring break-up of the river and the bay. Ice sheets created by melt-refreeze cycles in spring runoff sliding down the rock face may also contribute to this phenomenon. Prolonged exposure to salt spray is another possible inhibitory factor. These three situations impede the establishment of new individuals as well as remove spores by washing or scraping those off that do not establish.

The first lichen zone, which can be characterized as the Caloplaca elegans zone, indicates a tolerance, affinity or requirement for salt spray. Thomsen (1953) observed the same phenomenon in the Churchill area. He also found C. elegans growing inland on rocks where salt spray was carried for long distances by the frequent strong winds. The Caloplaca zone receives the smallest accumulation of solar radiation but the greatest snow cover which protects it from the harshest conditions during the year. The controlling factor for C. elegans distribution within this community is the salt concentration (Kappen 1974).

Parmelia disjuncta appears as a ubiquitious species, but on close examination its distribution is rather specific. It is lacking from the shallowest depressions where shading, moisture, nutrients and competition from other species occur. There seems to be an affinity for small local rock projections which have a dry exposed microenvironment. These projections also intercept a greater amount of solar radiation than the immediate surroundings, thus being warmer.

Intense competition apparently exists between P. sulcata and P. disjuncta. The two species appear to require the same microclimatic influences. Further investigation is required to study the microhabitat preferences of P. sulcata and its response to competition with other species.

Parmelia centrifuga is not well distributed or represented in this community which may be attributed to several factors. Perhaps the successional structure of the community has not yet reached the stage where P. centrifuga dominates. Perhaps Rinodina and its toxin (Ahti 1977) inhibits the growth and distribution of P. centrifuga. Much more study is required to determine the controlling factor of P. centrifuga distribution. Insufficient information is available from this study to make conclusions.

Umbilicaria arctica, the only foliose lichen present, was just beginning to establish a dominance halfway up the transects. This species appeared to be inhibited by Rinodina oreina and its allopathic toxin (Ahti 1977). This is one explanation for the lack of Umbilicaria on the highest elevations but the absence is more likely the result of microtopographic and microclimate influences. Umbilicaria was found on areas with a slightly lesser slope than the surroundings where moisture remains slightly longer than on the rounded summit. The growth form of U. arctica traps moisture beneath its thalli and intercepts incoming radiation preventing it from warming the rock and increasing evaporation. Umbilicaria aids in development of silt by trapping particles beneath the thalli thereby aiding in the next step in the successional sequence.

Rinodina oreina occupies the harshest microclimate of any of the species. The summit is windswept, dry, receives the greatest amount of solar radiation, experiences the greatest diurnal temperature fluctuations and receives the shallowest snow accumulations. Its growth form is an adaptation

to this harsh environment. The thalli is attached tightly to the rock surface.

The pattern of vegetation along such a ridge can be used to determine the age of the rock based on successional patterns (Magomeda 1979) and the long life of lichens (Billings and Mooney 1968). The general successional sequence for lichen communities was proposed by Magomeda (1979) and Ahti (1977).

crustose 1 → crustose 2 → foliose → fruticose

The community described here is placed at the crustose 2 stage succeeding to the foliose stage using Umbilicaria as the indicator species. Further back on the ridge, succession is at the foliose stage with a variety of Umbilicaria species covering a large area (Fig. 5).

The development of a rock-lichen community is dependent upon the properties of the rock and the environmental influences resulting from the rock properties.

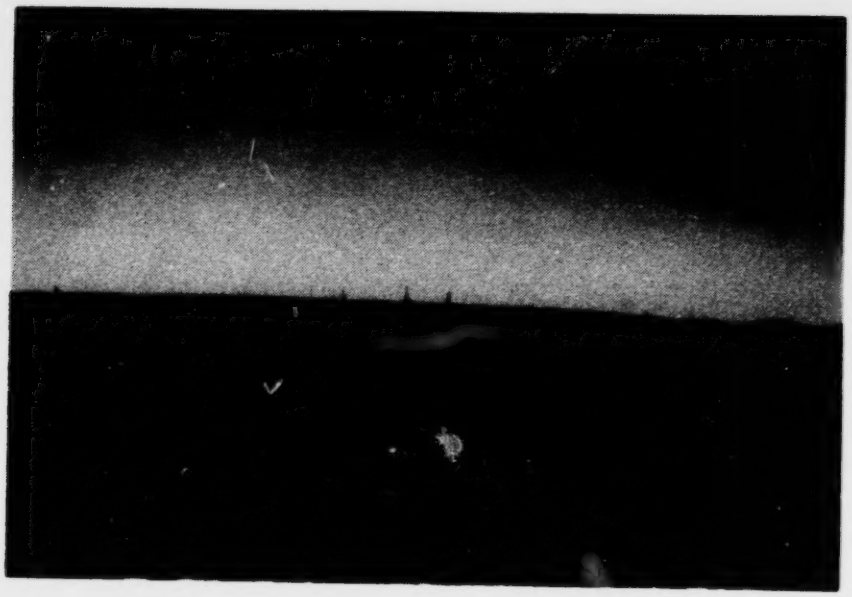


Figure 5: Umbillicaria spp. covering a Churchill quartzite ridge.

Salt Marsh

Salt marshes are a common community type along the coast of Hudson Bay and along the shores at the mouth of the Churchill River (Fig. 1). They generally begin at the high tide mark and extend inland about 1 km (Ritchie 1957). They are formed between the inland vegetation and the receding sea level. There is a gentle slope toward the bay of the relatively even terrain (Kershaw 1976). Small depressions occur throughout these small marshes (Ritchie 1957). Water supply is periodically replenished by the influx of tidal waters. The depressions impound water between tides forming tidal pools (Ritchie 1957)(Fig. 6).

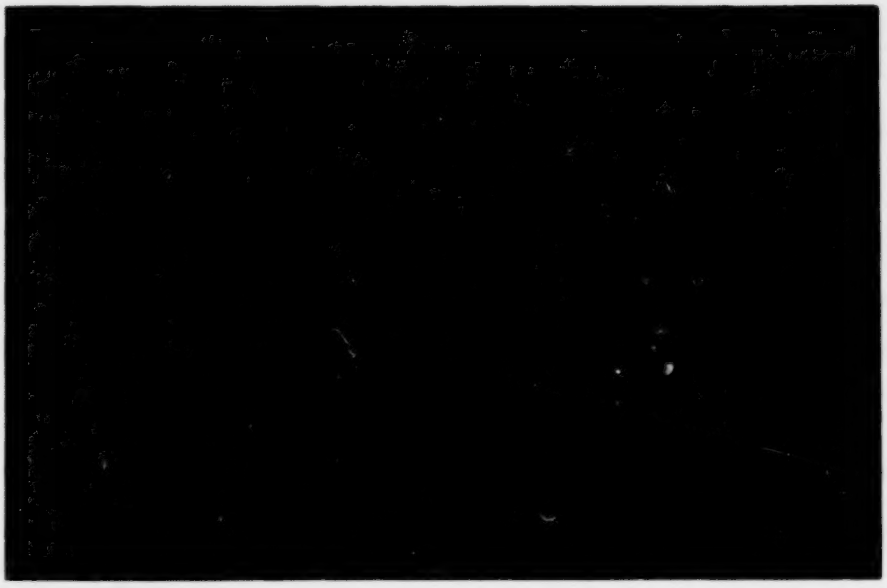


Figure 6: A tidal flat exhibiting numerous tidal pools.

These marshes undergo the harshest and most severe of conditions in the region. They are the last areas to be exposed during the spring due to the beached ice floes. The marshes are underlain by a layer of permafrost at increasing depths with increased summer temperatures (Kershaw 1976). The marshes are highly exposed and windswept throughout the winter when frost penetration is enhanced.

The tidal marshes or flats are the initiation site for beach ridges. Sands and silts are deposited at high tide marks, sometimes being trapped by the vegetation (Kershaw 1976). These ridges begin as strand lines often initiated around uplifted rocks.

Marshes at the mouth of the river have a somewhat thicker silt deposit of downstream origin than those on the coast which are mainly sand (Schofield 1959). The river mouth filters out much of the silt before it reaches the bay.

These wetlands have an increase in salt concentration toward the centre of the marsh when they peak and slowly drop off as one moves closer to the adjoining land. The greatest concentrations are found just above the high tide mark where surface water evaporates quickly concentrating the salt (Ringius 1980), which is not washed away with the next high tide. These concentrations are found as a white crusty layer on top of the soil.

Along the land edge a fresh water situation is found. This water supply is provided by runoff from the melting snow and frost, throughout the summer (Kershaw 1976).

Associated with these concentrations are distributions of halophytic vegetation. The periodic sea water fluctuations maintain the salt concentrations and thus the species distribution. Vegetation does not occur in distinct zonations but along a continuum from the high tide mark to the fresh water marsh-fen (Kershaw 1976).

Generally Puccinella phryganodes is found near the high tide mark and grades into Hippuris tetraphylla (Kershaw 1976). Depressions contain individuals of Potamogeton filiformis (Ringius 1980). H. tetraphylla intermingles with C. subspathacea, Potentilla egedii and Triglochin palustris as one moves inland (Ringuis 1980, Kershaw 1976). On the "salt pans" or "salt flats" where salt concentrations are highest, a number of halophytic species grow. Salicornia rubra, Suaeda depressa, Atriplex patula, Scirpus rufus, Festuca rubra, F. vivipara, Triglochin maritima, Senecio congestus, Ranunculus hyperboreus, Cicuta virosa, and Eleocharis spp. are among the more prominent species providing cover. On areas closer to the fresh water supply where the salt concentrations are diluted Hordeum jubatum, Juncus balticus, J. arcticus, Carex glareosa, Rumex occidentalis and Hippuris vulgaris are the indicative species (Ringius 1980, Kershaw 1976, Schofield 1959).

Old strand lines have a cover of Calamagrostis neglecta (Kershaw 1976). Newly formed beach ridges can often be found separating the vegetation associations. Upon these ridges grow Elymus arenarius and the beginnings of beach ridge succession (Ringius 1980, Kershaw 1976).

Freshwater marsh-fens are found close to the land where runoff supplies the fresh water. On these sites are found hummocks with their typical species distribution which will be discussed in following sections. Carex aquatilis, C. rariflora, C. diandra, C. chordorrhiza, Scorpidium scorpiodes, Potentilla palustris, Utricularia intermedia, Menyanthes trifoliata and several species of mosses are the major components of this community (Ringius 1980, Kershaw 1976, Schofield 1959).

Bordering this fen is a shrub zone composed of Betula glandulosa, Salix spp. and Myrica gale (Ringuis 1980, Ritchie 1957). Freshwater fens remain between the beach ridges as the land rises and develops the beach ridge lichen-heath community.

These salt marshes are used extensively by geese which feed on the shoots of goose grass (P. phryganodes). Those "tidal flats" are used by numerous species of shorebirds for the abundant invertebrate food supply (Ringius 1980, Kershaw 1976).

Beach Ridge - Tundra Heath

Beach ridges are formed by the recession of seas in combination with isostatic rebound. Inwashed sand, silt and boulders are deposited on the shore. As the waters recede, the ridge is left high and dry. Uplift continues, vegetative colonization, peat deposition and consolidation of the substrate among the most important developments take place, resulting in the present dry ridges.

Beach ridges of various ages and sizes can be found in the Churchill area. Their dry environments provide the foundations for most roads and structures, especially along the coast. The species distribution on the remainder of the ridges is dependent upon elevation, aspect, wind exposure, snow depth, peat depth, soil moisture and local topographic changes during development (Pierce and Kershaw 1976, Larson and Kershaw 1974). A special problem the vegetation must contend with is the influence of isostatic uplift. The land rebounds at a rate of approximately 1 m every 100 years (Hora 1977, Terasmae 1977, Cheney and Brown Beckel 1955), constantly modifying the micro-topography. The vegetation follows a distinct sequence from young coastal ridges, inland to older ridges (Fig. 7)(Rouse and Kershaw 1973). Beach ridges support the vegetation type commonly known as lichen-heath.

The species distributions over the ridges is governed by the edaphic and microclimate influences. Species dominance shifts position on the ridge in response to changes in soil moisture, exposure (Pierce and Kershaw 1976), and succession (Bliss 1960). The edaphic conditions are

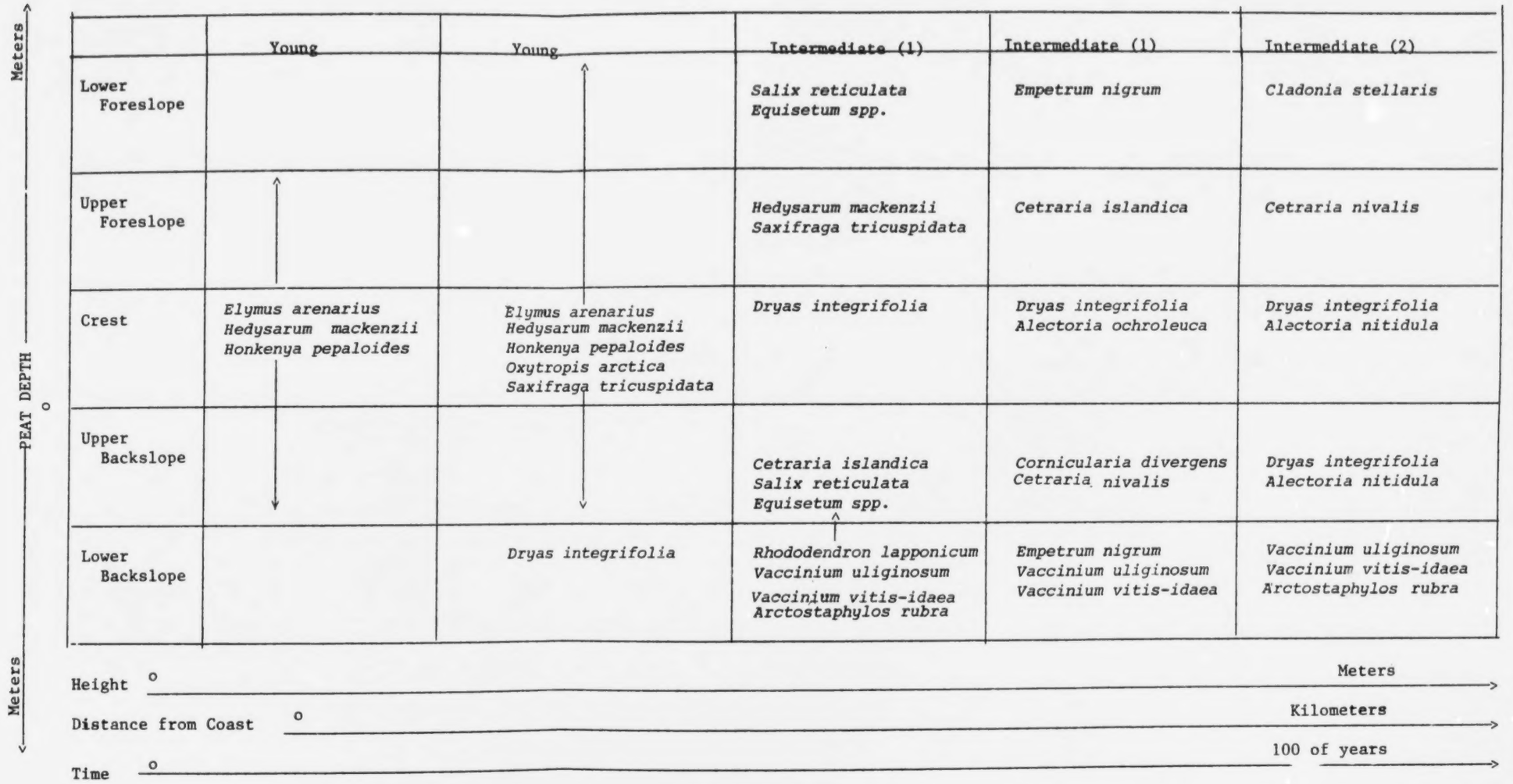


Figure 7: Diagram of beach ridge development stages.

influenced by the aspect of the slope, prevailing winds and snow drift. In Churchill the prevailing winds are north and northwest (Savile 1968), the ridges forming concentric arcs around the bay. The influence of wind on each ridge therefore differs with its aspect.

In general, on a young, low ridge, snow will blow up the foreslope over the crest and be deposited at the base of the backslope (Fig. 8). As the ridge rises with age, snow is trapped at the base of the foreslope, some blows over the crest and is deposited in varying quantities along the backslope. The most exposed microclimate is the crest (Larson and Kershaw 1974).

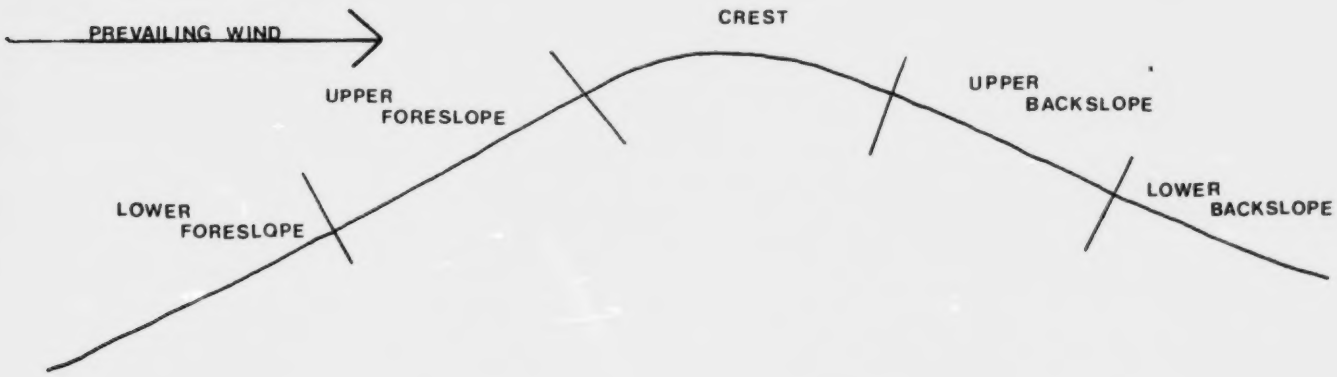


Figure 8: Cross-section of a beach ridge with arbitrary divisions indicated.

The increased snow cover in the areas mentioned provides a warmer environment in winter, and a wet, cool environment in spring and summer (Pierce and Kershaw 1976). Less exposure to wind, decreased evaporation, cooler environment and accumulations of runoff are more conducive to peat formation than the dry exposed crests. The development of peat, the alteration of moisture regimes and compaction of substrate is expressed by changes in the species distributions and composition on ridges of varying ages (Fig. 9).

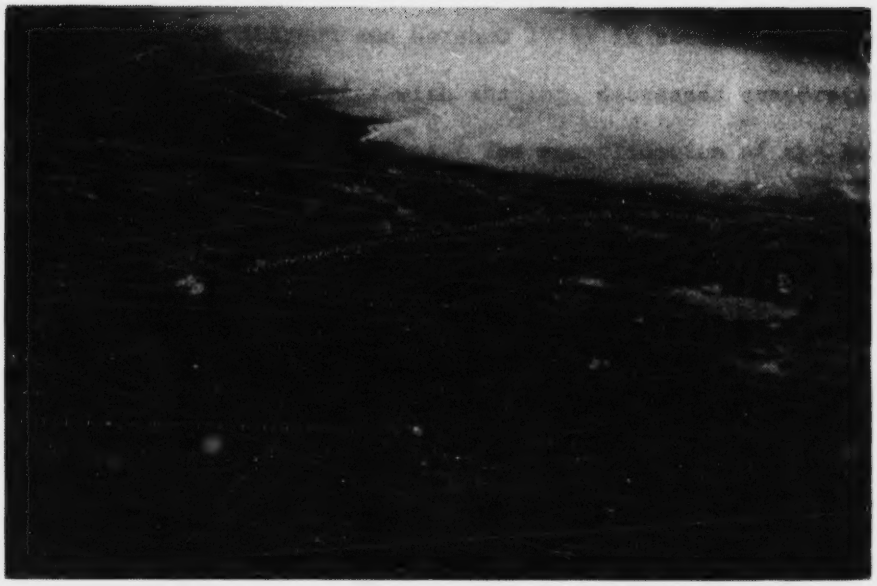


Figure 9: A former tidal flat now showing a succession of strand lines or the beginnings of beach ridges.

The primary colonizer on newly deposited sand and silt is Elymus arenarius (Pierce and Kershaw 1976). Its rhizomatous habit stabilizes the substrate and aids in compaction. This allows for greater moisture retention and creation of environments suitable for a variety of species. The rhizomatous mat intercepts drifting sand. It also intercepts snow on the windblown landscape, providing greater winter insulation and an environment more favourable for the survival and growth of additional species. E. arenarius dies out soon after the establishment of Hedysarum mackenzii, Honckenya pepaloides, and the initiation of peat formation (Pierce and Kershaw 1976).

A young ridge supports a community composed of a few remaining plants of E. arenarius, H. mackenzii, H. pepaloides, and Oxytropis arctica on the crest. Dryas integrifolia colonizes the lower backslope where peat deposits have begun and Saxifraga tricuspidata and Carex rupestris occur on the crest (Pierce

and Kershaw 1976). As the ridge continues to rise, peat accumulation increase and the moisture regime (Larson and Kershaw 1974) is altered under the vegetative cover. The surface remains cooler with shading, decreased evaporation and increased localized snow accumulations. The consolidation of the substrate and increased moisture content have a greater probability of frost heaving producing polygons and frost wedges. This generally occurs on the flatter portions of the foreslope where insulation by snow is less and frost penetration is deeper than on the backslope (Pierce and Kershaw 1976). These formations create yet additional microhabitat to be colonized (Neal and Kershaw 1973).

Slightly older ridges will still include D. integrifolia but the dominant zonation shifts to the crest where peat deposits and moisture content are lowest (Larson and Kershaw 1974). H. mackenzii is still found along the foreslope but in low numbers and decreased vigour. S. tricuspidata and Carex rupestris shifts its dominance to the upper foreslope as well. Cetraria islandica is the first lichen to colonize, growing on the upper backslope where peat deposits are thick and relatively moist (Pierce and Kershaw 1976, Larson and Kershaw 1974, Neal and Kershaw 1973).

Rhododendron lapponicum can be found at this state on the bottom backslope where peat depths and moisture retention are greatest due to snow accumulations, low evaporation and decreased wind exposure (Larson and Kershaw 1974). Vaccinium uliginosum, V. vitis-idaea and Arctostaphylos rubra are found in localized depressions, caused by frost action where peat, moisture and micro-topographic protection are greater (Neal and Kershaw 1973). Salix reticulata and Equisetum spp. show preferences for the backslope where moderate peat, moisture and exposure levels occur (Pierce and Kershaw 1976).

An intermediate-aged ridge has increased elevation. Significant peat deposits occur at various locations over the ridge, moisture content has changed

and vegetative cover and physical features have altered drastically from the initial states. New species and species shifts are still seen.

S. tricuspidata and H. mackenzii have died out in response to the environmental changes and competition. C. islandica has shifted its dominance to the exposed, well-drained upper front slope (Pierce and Kershaw 1976). Cornicularia divergens has taken up residence on the upper backslope and Alectoria ochroleuca joins Dryas on the crest. Dry, well-drained, slightly exposed conditions lead to the establishment of Cetraria nivalis on the upper backslope. Empetrum nigrum is often found on the moist, protected bottom slopes (Pierce and Kershaw 1976).

The second intermediate stage brings the establishment of Cladonia stellaris on the lower slopes with E. nigrum, V. uliginosum and V. vitis-idaea where peat, moisture and snow accumulations are high and wind exposure low (Larson and Kershaw 1974). Alectoria nitidula replaces A. ochroleuca and accompanies D. integrifolia on the crest where evaporation rates and wind speeds are high (Larson and Kershaw 1974). C. nivalis moves to the upper front slope.

An old beach ridge may reach a great height, 70-90 m, as those of the Tyrell Sea. An old ridge usually supports a growth of Picea spp. with a carpet of C. stellaris to the exclusion of other species. A spruce-lichen woodland is the result.

Nutrient availability and p^H plays a small role in determining the species distributions. Initially, the soils are alkaline owing to leaching from the underlying limestone. However, as acidic peat is deposited and leaching occurs from the ridge top, a buffering effect may take place resulting in an almost neutral soil (Neal and Kershaw 1973). There is little variation from bottom to top of the slope or along a developmental gradient (Pierce and Kershaw 1976). Nutrients and p^H can be classified as minor limiting factors.

Each ridge and ridge system possesses its own characteristics; the preceding was a general description based on zones and associations defined by Pierce and Kershaw (1976) and Neal and Kershaw (1973). Localized variations are dependent upon the stability of the soil, frost action, disturbance, mechanical and natural, and enrichment (Rouse and Kershaw 1973). The greatest environmental influence is elevation (Pierce and Kershaw 1976), including microtopography, soil, peat depth and organic material.

Spruce-Lichen Woodland

Spruce-lichen woodland is another stage in the maturation process of a beach ridge. Two types have been described in the subarctic this far, Cladonia stellaris-Picea glauca, and Stereocaulon pascale-Picea glauca woodlands (Kershaw 1977). Stereocaulon woodlands appear to be the more northerly and westerly type while Cladonia stellaris is the eastern and southern type (Kershaw 1977).

These woodlands are usually formed on well-drained sandy substrates, beach ridges or outwash plains (Kershaw 1977). A brief survey of Cladonia stellaris-Picea glauca woodland was made on September 1, 1981. Two separate sites were examined, both located at the base of the Churchill quartzite ridge, one on the east slope and the other on the west facing Button Bay (Fig. 11).

The west woodland was situated on a gravel-sand Tyrell Sea beach ridge. The terrain was uneven. Maximum height of the ridge was 46 m. The woodland appears as a dense white spruce forest with numerous openings and extensive Cladonia stellaris ground cover with patches of Ledum groenlandicum, Vaccinium vitis-idaea, V. myrtilloides and Arctostaphylos rubra (Fig. 10). These are remnants of the previous beach ridge community.

The lichen mat was thick (.75 m) and spongy. Top layers were warm and dry while underlying layers were cool and moist. Within the stands of spruce

the atmosphere was cool and moist with little light penetration; openings were warm and bright. In a few localized areas of better organic soils and more acidic p^H, Linnaea borealis, Geocaulon lividum, Juniperus communis and Loiseleuria procumbens, were found in addition to the remnant species previously mentioned. Under the intense shade of the trees there was a greater frequency of mosses.

Figure 10: A maturing spruce-lichen woodland with a white spruce (Picea glauca) canopy, a lichen (Cladonia spp.) mat in association with ericaceous shrubs.

Fire plays an integral part in maintaining and rejuvenating the spruce-lichen woodland as it does in southern boreal forests (Wiens 1975). Much smoke and ash were evident in the atmosphere the week previous to the investigations. The cause of this condition was briefly examined. The last smouldering peat layer was observed in the east slope woodland. Over most of the burned area all organic cover was removed, charred trees were numerous and the peat layer was burned to the mineral soil except on the well-trodden and consolidated path (Fig. 11).

Figure 11: The aftermath of fire in a spruce-lichen community.

Rejuvenation or revegetation after fire is a much slower process than in southern boreal regions. Epilobium angustifolium, the prolific indicator of burns and disturbance in the south, is all but absent in the north. Infrequent pockets of this species occurs when microclimate and microtopography are favourable. The soil surface, however, will remain bare for two to three years due to the extremely harsh conditions that exist (Maikawa and Kershaw 1976).

With all forms of insulation removed the bare soil is exposed to the extremes of the climate. The dark black surface has a low albedo, absorbing much of the incoming solar radiation and reflecting little (Kershaw 1977). Surface temperatures may increase to lethal levels during the summer days; 50.8°C has been recorded by Kershaw (1977). Much of the stored energy is reradiated at night causing large diurnal fluctuations.

Little rain falls in the subarctic. The fate of the small amount that does fall on the burned surface is unfavourable to vegetative growth. The lack of organic cover allows much of the rain to run off. Some percolates into the ground but sand has a small holding capacity (Washburn 1980). With this runoff go many nutrients; these are increasingly depleted with additional runoff. Nitrogen and phosphorus are particularly affected. The high quality runnoff is a boon to the surrounding lands into which it drains and productivity increases there with the increased nutrient supply (Wiens 1975). Initially, much erosion also takes place with the lack of impedence. Surface moisture is quickly evaporated with the high temperatures and increased exposure but soon decreases with decreased capillary conductivity (Rouse and Kershaw 1971). Desert-like conditions prevail with dust storms occurring for the first two summers (Rouse and Kershaw 1971). Physiologically, the early colonizers must survive and grow in an environment of great thermal stress, approaching characteristics of a hot desert (Kershaw 1977).

Winters are also dry and harsh. Without trees and vegetation to trap and hold snow the surface becomes windblown with a very thin insulative covering.

The following spring available moisture is soon absorbed by the ground. Evaporation is initially high but with increasing dryness, evaporation decreases over the bare surface due to decrease in capillary conductivity (Rouse and Kershaw 1971). There is less summer runoff, both on the surface and subsurface, from the burned area than from the lichen-covered surfaces.

In 2 or 3 years, a few shoots develop from rhizomes buried in the ground (Maikawa and Kershaw 1976, Wiens 1975). Vaccinium vitis-idaea, V. myrtilloides, Ledum groenlandicum, Shepherdia canadensis and a few crustose lichens (Maikawa and Kershaw 1976), requiring minimal moisture and nutrients, begin to grow (Kappen 1974, Billings and Mooney 1968). Regeneration is slow, unaided by the short growing season.

Nutrient availability is another factor limiting growth. Nutrients held by lichens are available to vascular growth after burning. A faster recycling occurs with annual deposits of herbaceous aerial structures. Recovery of nitrogen and phosphorous in particular, is a slow process (recovery of nitrogen after six years can be as low as 10% of prefire conditions). Phosphorous recovery is somewhat better, being reduced to 10 or 15% immediately following burn and recovering to 60-70% after 6 years (Wiens 1975). This is an indication of the barriers to vegetative recolonization. It takes at least 14 years for soil to return to the pre-fire state (Kershaw 1977).

Populus balsamifera and E. angustifolium will grow in the few areas of favourable microtopographical influence near Churchill. They are slightly more protected with marginally richer soil, with a clay base and a slightly higher moisture level. Reproduction is by rhizomes; therefore recovery after

fire is accomplished easier than for spruce. The establishment of vegetation helps to entrap snow, improve moisture conditions, decreases erosion, leaching, surface temperatures and increases peat deposits. Permafrost initially is not a major influence on vegetation re-establishment on the sandy substrate. Its influence increases with improved insulation and moisture retention.

Approximately 75 years after fire, spruce seedlings begin to establish in the moist cool substrate of the devloping lichen mat. After another 75 to 125 years a spruce-lichen woodland, is well established (Fig. 10). As the C. stellaris cover becomes more extensive, it exerts an inhibitory effect upon the establishment of spruce seedlings. This is in the best interest of the lichens because they cannot withstand shading. Mosses invade when shading occurs (Maikawa and Kershaw 1976, Kershaw 1977).

Mature spruce trees resort to tillering about 250 years into the re-establishment of the woodland. The lichen mat increases to such a depth the bottom branches of the trees are nearly consumed; they respond by tillering into the mat, creating concentric rings of daughter trees around a mother tree. Eventually a dense spruce forest is produced intercepting radiation and precipitation and preventing it from reaching the ground. At this time (400-500 years post fire), C. stellaris is out-competed by mosses and a spruce-moss woodland grows (Kershaw 1977). This happens very infrequently since another fire usually occurs before this stage sets in. Fires are commonly started by lightning but are increasingly the result of human activity (Wiens 1975). The dry lichen is a highly flammable fuel through which fire spreads quickly, burning into the peat and melting permafrost (Wiens 1975). The exact regeneration sequence of any spruce-lichen woodland is dependent upon the severity of the fire and local climatic conditions.

Fen-Bog

Fen-bogs or sedge meadows are a common landscape feature of the Churchill area. This vegetation community is typical of the tundra or barrens (Fig. 2).

Sedge meadows or minerotrophically rich fens are formed initially on the edge of maturing salt marshes as previously described (Kershaw 1976, 1974b). As the land uplifts and beach ridges become more prominent these lowland areas remain between them (Kershaw 1974b). They collect the mineral rich runoff from the surrounding higher ground. Evolution of the fens can be traced along the same sequence as beach ridge development.

The fens are usually covered by less than 50 cm of standing or slow moving water (Kershaw op. cit.). A peat layer, of varying thickness, lies over the limestone-marine clay substrate. The environment is alkaline in nature with a p^H greater than 7.5.

The amorphous peat is composed of deposits of algae, particularly Nostoc spp., the moss Scorpidium scorpioides and Carex aquatilis, the dominant vascular species. The rhizomatous growth habit of C. aquatilis contributes to the peat deposits and aids in substrate consolidations. Some of the less dominant and more widely distributed species include Menyanthes trifoliata, Potentilla palustris, Equisetum spp., Triglochin palustris and Parnassia multiseta (Kershaw 1974b).

Accumulations of peat, cryoturbation and isostatic uplift raise portions of the fen where drying occurs. In these areas new species are able to colonize; among these are mosses, particularly Sphagnum spp. The accumulation of Sphagnum peat lowers the p^H considerably to 7.5-6.2 (Kershaw 1974b). In addition to some of the species already mentioned Scirpus cespitosus is found in response to decreased water levels. Other species occuring at this

stage are Eriophorum scheuchzeri, Carex capillaris, C. diandra, C. saxatilis, C. glareosa and C. rariflora.

Sphagnum peat continues to accumulate decreasing the pH to below 6.2 as well as increasing the height of the hummock above the water table (Ritchie 1960c). At this stage calcifuge species such as Betula glandulosa and Salix spp. form a scrub bush; however, some of the more tolerant calcicole species persist. These include C. capillaris, Equisetum spp. and Triglochin palustris. New species are Tofieldia pusilla, ericaceous shrubs Empetrum nigrum, Andromeda polifolia and Ledum groenlandicum (Ritchie 1960c).

Larix laricina is able to invade this modified habitat with the ericaceous shrubs and mosses covering the ground (Ritchie 1960c). Eventually the larch trees die out and are replaced by Picea spp. with a change in moss species to Hylocomium spp., Dicranum spp. and Hypnum spp. (Ritchie 1960c). This open spruce forest will then succeed into an open lichen bog once the active layer becomes too thin to support tree growth (Ritchie 1960c).

Gradations of vegetation can also be seen along the edges of the beach ridges. Along the wet margins and in depressions Empetrum and Ledum are found as has been described.

Seasonal frost penetrates deep into the substrate beneath these fen communities meeting the permafrost, as they are open and windswept with little winter insulative cover (Brown Beckel 1957, Kershaw 1974). Fens also have a somewhat thicker active layer than those under palsas and peat plateaus due to the different peat types and the higher heat conductivity of water (Kershaw 1974b). Fens however, remain cooler than the sandy ridges in summer since sand has a higher coefficient of heating than water (McFarlane 1969).

The saturated fen peat and soils are subject to frost action on freezing. Several periglacial structures are common within these fens. Some

of these are hummocks, palsas, peat plateaux, patterned ground including sorted and non-sorted polygons, stone nets, high-centred and low-centred polygons (Washburn 1980).

Hummocks

Hummocks are rounded mounds found in the subarctic and the arctic usually less than 60 cm high and covered by vegetation. They can be composed of either mineral soil or peat (Washburn 1980, Brown 1977, Lundqvist 1969). Peat hummocks usually contain boulders as a major component of the mound (Raup 1963). Peat hummocks are the characteristic type in the Churchill area and will be the major topic of discussion.

A hummock fen adjacent to Landing Lake Road (Fig. 1) was briefly studied between August 27 and September 2, 1981. The general area was an open expanse of fen with relief provided by various sized mounds. Sizes ranged from tussocks dominated by Carices to larger structures covered by ericaceous shrubs and lichens. The largest mounds were occupied by Picea spp. and L. laricina.

Unlike many of the periglacial structures to be discussed, permafrost is not required to maintain these hummocks. They are a biogenic phenomenon because of the diffrential growth of vegetation and peat formation (Lundqvist 1969).

Hummocks are usually found in wide expanses of fen. Various sizes of these structures can be found at any one time. A typical distribution within a portion of a hummock fen is on Figure 12 (pg. 47). Hummocks may remain separate entities or coalesce to form other structures, palsas, string bogs and perhaps peat plateaux (Lundqvist 1969). The specifics of their initiation and formation influence their eventual evolution into other structures. The main requirement for their formation is a supply of gently flowing water throughout the frost-free period (Raup 1963). Water is usually abundant in the fens in which

hummocks form. In addition, most hummock areas form on a slope of 1° to 15° (Raup 1963). There is a general incline of the land towards Hudson Bay. Mass wasting or slope solifluction provide beginnings of hummocks (Egginton 1979). Hummocks and their complexes form perpendicular to the slope (Lundqvist 1969, Sjors 1959). The accompanying diagram shows an orientation of hummocks toward the WNW-ESE (the slope is N-S flowing into the bay).

The rich fen (Slack et al. 1980), dominated by Scorpidium scorpioides with scatterings of C. aquatilis (Kershaw 1974b), lies overtop marine clay, till and limestone making its alkaline in nature. Little insulation in the form of snow accumulates on the open landscape (Brown Beckel 1957) and the saturated substrate is subject to intense frost action.

Cryoturbation frequently pushes rocks up to and above the soil surface in annual freeze and refreeze cycles (Raup 1963). Rocks are incorporated into many hummocks (Raup 1963) as were found in the present investigations. The microrelief supplied by the protruding rocks provides a site for the accumulation of organic material carried by the water (Raup 1963). When water levels drop off or when rocks rise above the water level peat accumulations reach the water surface and become exposed, whereupon new species of mosses and vasculars are able to colonize. Kershaw (1974b) and Slack et al. (1980) describe this trend with a shift from S. scirpioides, submersed in the deepest part of the fen, to Drepanocladus revolvens submersed in shallow water, to Campylium stellatum forming small emergent hummocks. Peat continues to accumulate and the hummock increases in size. Scirpus cespitosus, Carex capillaris, C. diandra, C. magellanica, C. rariflora, C. saxatilis and C. aquatilis begin to grow on these tussocks (Kershaw 1974b). Additional height is gained by expansion of the freezing saturated soils within the core, after the surrounding fen is frozen (Raup 1963).

Hummocks may be initiated in a depression caused by rocks which act as heat sinks, melting the frost. These depressions then become filled with organic material which begin the peat accumulation and the growth of a hummock.

Hummocks can generally be separated into three size classes which are:

Large - greater than 40 cm high, 2.0-2.5 m wide

Medium - 30-40 cm high, approximately 1 m wide

Small - tussocks less than 30 cm high, less than 1 m wide

Eventually, adjacent small hummocks coalesce to form one larger hummock (Coombe and White 1951). This was evident in the medium and large hummocks sampled where the uneven microtopography showed evidence of former smaller mounds. Ridges or strings were formed where a number of coalescing tussocks occurred perpendicular to the slope (Raup 1963).

Large peat accumulation and associated height increases do not occur until mesophytic mosses (i.e. Tomenthypmum nitens and Sphagnum spp.) colonize the drying peat mounds (Raup 1963). This could be seen by the differential peat deposition in the various sized sampled hummocks. Hummock excavations revealed the presence of a number of granite rocks and boulders in and above the marine till layer within the mounds. The average peat thickness in a large hummock was 25.3 cm and in a second 13.3 cm. The average peat depth in the fen was 16.65 cm. A medium-sized hummock revealed an average peat thickness of 25.5 cm. Small hummocks or incipients were clumps of turf or sod covered by a thin layer of peat sitting on the fen surface or often situated over a rock.

There was a difference in the texture of peat and moisture content between the hummocks and the fen. Hummock peat of Sphagnum moss origin was fibrous, coarse and dry while fen peat from herbaceous material and S. scorpioides origin was amorphous and saturated.

There is a trend toward acid peat as each moss species dies out and

new ones replace them (Kershaw 1974b). The growth of Sphagnum spp. over the top of the hummock has a great influence on acidification and height increase (Coombe and White 1951).

Community types can be distinguished on developing mounds as they increase in size and the persistence of zonations around the larger hummocks. In the fen which is covered by water the dominant species are Scorpidium scorpioides and Carex aquatilis. This level is used as the zero mark when discussing elevation and height relationships. On the slightly raised portions of the fen 10-20 cm above the baseline, covered by shallow water, S. scorpioides, C. aquatilis, Scirpus cespitosus and moss species are the dominants. On small tussocks 20-30 cm above the baseline, mosses, various Carex spp. including C. capillaris, C. diandra, C. magellanica, C. rariflora, C. saxatilis, C. scirpoidea and S. cespitosys provide cover.

With the height and p^H change, conditions are favourable for the colonization of new species. Mosses remain prominent and Andromeda polifolia, Tofieldia pusilla, Equisetum spp. and V. uliginosum are the major vasculars (Slack et al. 1980, Kershaw 1974b). This stage of development was observed between 31 and 40 cm.

Further height increase and p^H decrease leads to the establishment of Sphagnum warnstofii and S. fuscum (Slack et al. 1980). This zone, at 41-50 cm elevations was dominated by Vaccinium vitis-idaea, Empetrum nigrum, Andromeda polifolia; accompanying species included Rhododendron lapponicum, Cornicularia divergens, V. uliginosum, C. stellaris, Cetraria cucullata and Alectoria ochroleuca (Figs. 12 & 13). Kershaw (1974b) indicated Empetrum spp. dominating on hummocks with a p^H less than 6.3 in comparison to a p^H greater than 7.5 in the surrounding fen. The maintenance of the low p^H level is mostly due to the deposition of Sphagnum peat, which also contributes to the significant increases in height.

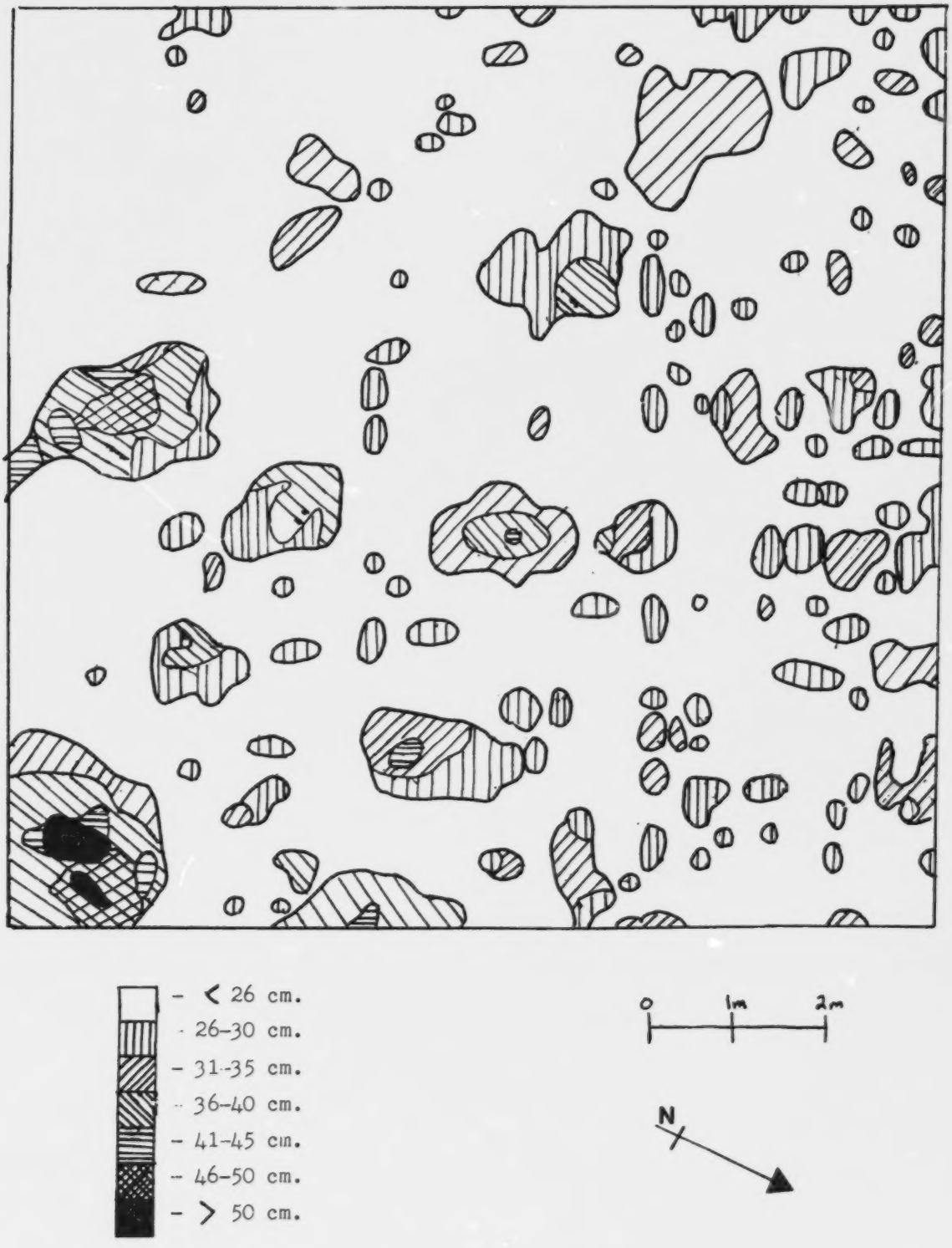


Figure 12: A sample distribution of hummocks and their relative heights.

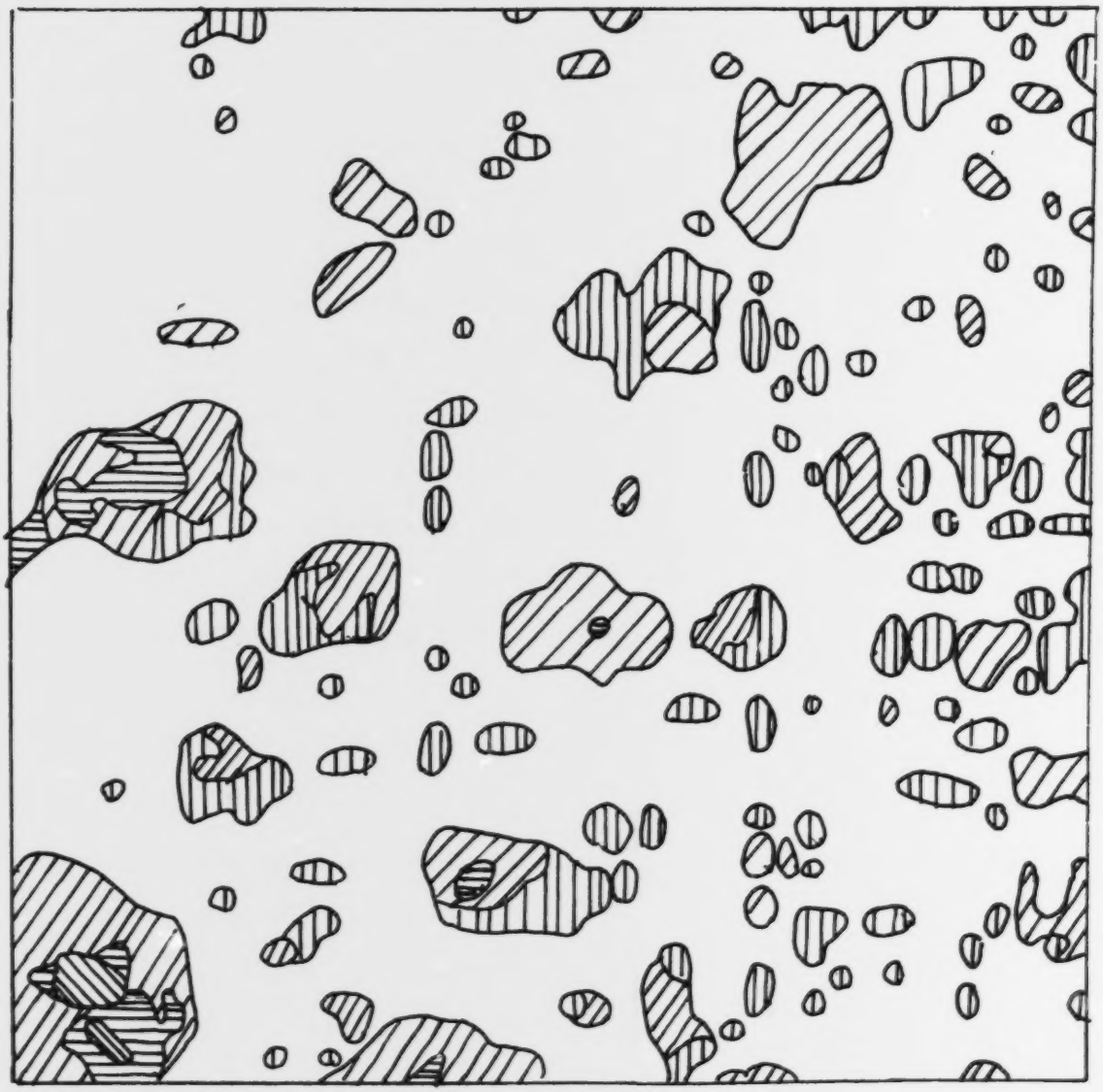

0
1m.
2m
N
-- Scorpidium scorpioides - Carex aquatilis
-- Scorpidium scorpioides - Scirpus cespitosus - Carex spp.
- Scirpus cespitosus - Scorpidium scorpioides -- Carex spp.
-- Vaccinium vitis-idaea - Empetrum nigrum - Andromeda polifolia
-- Cornicularia divergens - Vaccinium vitis-idaea - Cladonia stellaris

Figure 13: Vegetation distribution over a sample of hummocks.

A Cornicularia divergens-Vaccinium vitis-idaea-Cladonia stellaris association can be found at heights between 50 and 60 cm. Included in this association are Cetraria nivalis, Cetraria cucullata, Sphagnum spp. and Carex rupestris, C. glacialis and C. scirpoidea.

Hummocks rarely reach more than 60 or 70 cm in height (Raup 1963). The summit of these hummocks was usually dominated by lichens (Kershaw 1974b), two of the most prominent being C. nivalis and C. divergens, which are adapted to dry exposed habitats. Hummocks of this size usually possess sufficient insulation of Sphagnum peat to retain permafrost cores anchored to the mineral soil year-round. These structures are then called palsas. In investigations of various sized hummocks in the study area a minimum size of 3 to 4 m wide and greater than 60 cm high was needed to show evidence of permafrost. The permafrost observed was 1.5 to 2.0 m below the hummock surface.

Special cases have been documented (Lundqvist 1969) where permafrost has remained under smaller structures entirely within the peat layer. These structures may be the beginnings of peat plateau rather than palsas but as yet they are not well studied.

Development of hummocks may be halted at any stage, the primary cause being an alteration in drainage pattern (Raup 1963). The large sampled hummocks appeared to be near the maximum development for the given locality before undergoing transition into a palsa.

Degradation takes place when excessive drying and erosion occurs due to exposure and changes in moisture regime (Raup 1963). This can happen when the summit rises above the snow level where insulation is absent and abrasion increases or when lack of moisture, as in 1981, occurs. These effects could be seen at the experimental site. Cracks were beginning to form in the dry peat and erosion of the edges could be seen.

Prevailing winds and snow accumulation will continue to shape the community and determine its longevity. The flat tops on the large hummocks indicate the average snow level (Fig. 14). Snow accumulations contribute to the incline and drop off areas of the hummocks as well as the distributions of permafrost and species affinity. Permafrost regimes may be different on the north and south facing slopes of peat mounds (Pruitt 1978) due to the lesser snow cover on the north side of the mound. This condition also leads to different distribution patterns for species around the mounds. For instance C. stellaris would likely be more dominant on the southeast side of the hummocks, while Alectoria spp. are more prone to grow on the windward site. The more shallow active layer on one side of the mound compared to the others also inhibits the rooting ability and metabolic rate of vasculars. The restriction of vegetation growth influences the rate at which peat is laid down.

Figure 14: A large hummock exhibiting various vegetation associations. The flat top indicating the average snow level.

Hummocks may be useful in determining the water flow pattern in relation to slopes when considering construction on the tundra. Future development should consider the implicit signs of environmental stability expressed by the various communities developed on the landscape. Present use of hummocks includes roosting sites for geese and habitat for small mammals.

Palsa Bog

A palsa is a steep-sided mound of either peat or soil, up to six or seven metres high, usually less than 100 m across with a frozen centre that may be extensions of permanently frozen peat and underlying mineral soil (Washburn 1980, Pruitt 1978, Stanek 1977, Zoltai 1972, Lundqvist 1969). Peat ice core palsas are common landscape features in the Churchill region. Their peat surface is covered by mosses and a variety of vascular plants and lichens depending upon the age and developmental history of the structure. A brief study was made of such a structure.

Palsas in the Churchill area are maintained by permafrost centres but the long and hot summer of 1981 appeared to have altered this condition. The degradation, as described by Brown (1977) and Railton and Sparling (1973). This is but one stage in the developmental sequence of a palsa.

In the fen-bog, which is covered by a few centimetres to 30 or 40 cm of water in a normal year, peat deposits are formed from the Carex spp. and algae. A thick amorphous peat mat is formed. The palsa first undergoes development as a peat hummock protruding above the water level of small ponds and fens, less than 1 m deep (Brown 1968).

These mounds are formed by differential frost heaving of the saturated soils and peat in the fen as well as ice lense growth within the mineral layer (Washburn 1980, Brown 1977, Lundqvist 1969). The height gained by palsas are the result of segregated ice within the mineral soil (Washburn 1980, Brown 1977, Railton and Sparling 1973, Lundqvist 1969).

Being raised above the water's surface in the spring and summer exposes the peat mound to wind and sun and their drying effects. There is no living vegetation on the dry, high p^H peat surface of a young palsa (Brown 1977, Zoltai 1972). With subsequent winters the height of the palsa increases and vegetation colonizes the mound during the summer in the manner described for hummock development.

Among the first species to colonize the exposed amorphous peat are mosses and later being dominated by species of the genus Sphagnum. Their growth and eventual deposition of fibrous peat alter conditions by decreasing p^H, increasing moisture gradients and insulation for the underlying permafrost. The environmental changes lead to favourable conditions for the establishment of vasculars and lichens (Brown 1977).

Ericaceous shrubs and Picea spp. establish when conditions on the hummock are favourable. As the tree cover increases, shading also increases, providing an environment for intolerant lichen species such as Peltigera spp. The continued deposition of peat aids in insulation for the underlying permafrost allowing it to remain year round. Aggradation of the ice lenses continues with free water from the surrounding fen being pulled toward the freezing centre by capillary action at the beginning of each winter (Washburn 1980) eventually increasing in size to become a palsa.

The centre of the palsa continued to rise, eventually being higher than the snow level, remaining highly exposed and dry throughout the summer. During the winter, exposure allows greater frost penetration while edges are insulated by deep snow layers (Salmi 1970).

These conditions become unfavourable for trees due to the decrease in thickness of the active layer, and they eventually die out. The low ericaceous shrubs are able to remain owing to their growth form. As the canopy opens, lichens invade the drier, more exposed environment. Species such as Cladonia

stellaris, C. rangiferina and Cetraria nivalis are able to survive on the lower moisture levels with a higher degree of exposure (Sjors 1959). C. stellaris is adapted by creating a thick mat which sets up its own phytomicroclimate to entrap moisture and reduce temperature fluctuations (Rouse and Kershaw 1973).

Trees are maintained on the edges of the palsa where snow accumulations and moisutre levels are higher and the active layer is thicker.

In the transition zone between fen and palsa, B. glandulosa and Salix spp. remain where insulative snow cover and water supply are abundant.

Adjacent palsas may coalesce forming large complexes known as raised bogs or string bogs (Lundqvist 1969).

Palsas continue to grow and support vegetation until a perturbation from the norm causes a change in heat balance making it a positive relationship (Railton and Sparling 1973). Disturbance of the peat layer, i.e., tunneling by animals (Shelford and Twomey 1941) or removal of the vegetation will cause this. (Unlike hummocks, palsas cannot remain without permafrost). It results in excessive drying of the peat. The insulating ground cover splits, exposing oxidized peat, and general deterioration takes place as the permafrost begins to thaw (Brown 1977, Railton and Sparling 1973). The surface produces undulations due to differential thawing of the underlying ground ice (Brown 1977). Calving of peat blocks may also occur on the palsa edges. These blocks eventually sink into the surrounding fen (Railton and Sparling 1973). The complete process is a post-glacial phenomenon and takes at least one hundred years due to the short growing seasons.

The palsa under investigation was between the mature and degradation stage with a diverse and complete vegetation cover and a surface showing characteristic undulations (Fig. 15) caused by permafrost melt.

Evidence of permafrost was not found in two excavated soil pits. This could be the result of the warm, hot summer or perhaps a minimum sized structure

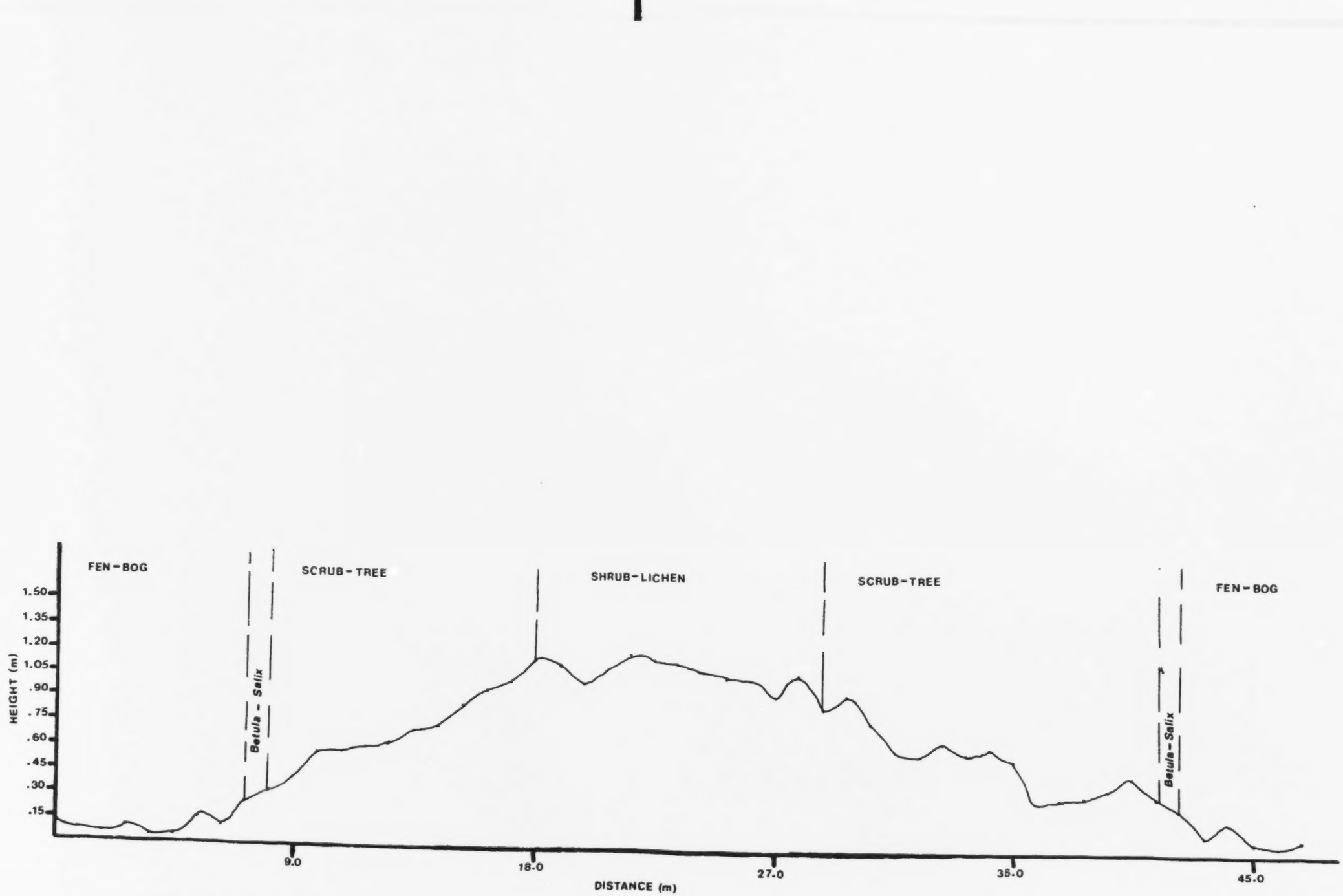


Figure 15: Cross-section of a palsa and distribution of vegetation associations.

is required to preserve permafrost throughtout the summer. According to Brown Beckel (1957) the average depth at which permafrost was found under mounds and palsas near Churchill was 80-180 cm below the surface as opposed to 110-250 cm in the wetlands. The soil pits probably were not deep enough to encounter permafrost as it was found 150-200 cm below the surface of the sampled hummocks.

Uses of palsas by wildlife include roosting sites for birds and provide habitat for small mammals and a food source for caribou.

Peat Plateau

Peat plateaux are elevated, flat peatlands, having a perennially frozen core (Zoltai 1972). In the Hudson Bay Lowlands peat plateaux can vary height from 1 m to 5 m (Zoltai 1972, Brown 1968), and cover an area of 1 km^2 (Stanek 1977, Schenk 1970). A medium-sized peat plateau was studied in the Churchill area.

The shape and vegetation composition of the peat plateau is the result of the developmental processes of the structure. Zoltai (1972) has defined and named the steps in this development.

The "incipient" stage occurs under dense black spruce in a fen. Vascular species cannot grow in the dense shade; only a few lichens such as Cladonia unicalis, C. cornuta and Sphagnum mosses are found. There is little relief and the area may even be slightly depressed. Shallow snow under the trees allows greater frost penetration compared to the surroundings with a thicker snow cover. Accumulation of peat provides increased insulation during the summer and maintains the frost for an extended time. Lense growth occurs at the beginning of winter with free water. Doming is a consequence of the increased volume of water on freezing (Pruitt 1978).

A "young" peat plateau appears as a low mound, less than 20 cm high. Open black spruce stands accompanied by Ledum groenlandicum, Cladonia

rangerferina, C. stellaris and mosses are found on an increasingly acidic substrate (Zoltai 1972).

In subsequent years, with the increase in Sphagnum peat thus insulation and height, the ice lense remains in the peat layer year-round (Zoltai 1972). Lundqvist(1969) described this phenomenon as a pseudo palsa and Salmi (1970) found such a structure in Finland. The increase in height is related to the increasing accumulation of Sphagnum (Heinselman 1970) and the buoyancy of peat and gases.

The plateau continues to grow and take on the characteristic flat shape. A "mature" plateau is high (1 m or greater) with local undulations. It may extend over several kilometers. Characteristic vegetation are open stands of black spruce and lichens (Zoltai 1972) ringed with a closed black spruce community (Sjors 1969) as indicated on Fig. 16.

A mature peat plateau was the developmental stage of the sampled structure. The changes in vegetation structure may be attributed to the changes in environment caused by the vegetation and underlying ice lense.

The outer ring of a closed black spruce-moss community remains because the active layer is still deep and moist enough to support the growth. As the Sphagnum peat layer thickens insulation values increase. The result is a decreased depth of seasonal melt with the ice lense remaining close to the surface. The sampled lense was within 40 cm of the surface. The shallow active layer creates a barrier to tree growth with low temperatures in the root zone, a dry environment and restricted nutrient availability. The frozen substrate also acts a physical impediment to root growth. As the canopy opens, lichens whose growth habits do not require rooting become established on the surface. On the surface of the essentially dry peat Cladonia stellaris creates its own moist temperature regulated environment making it very successful. The

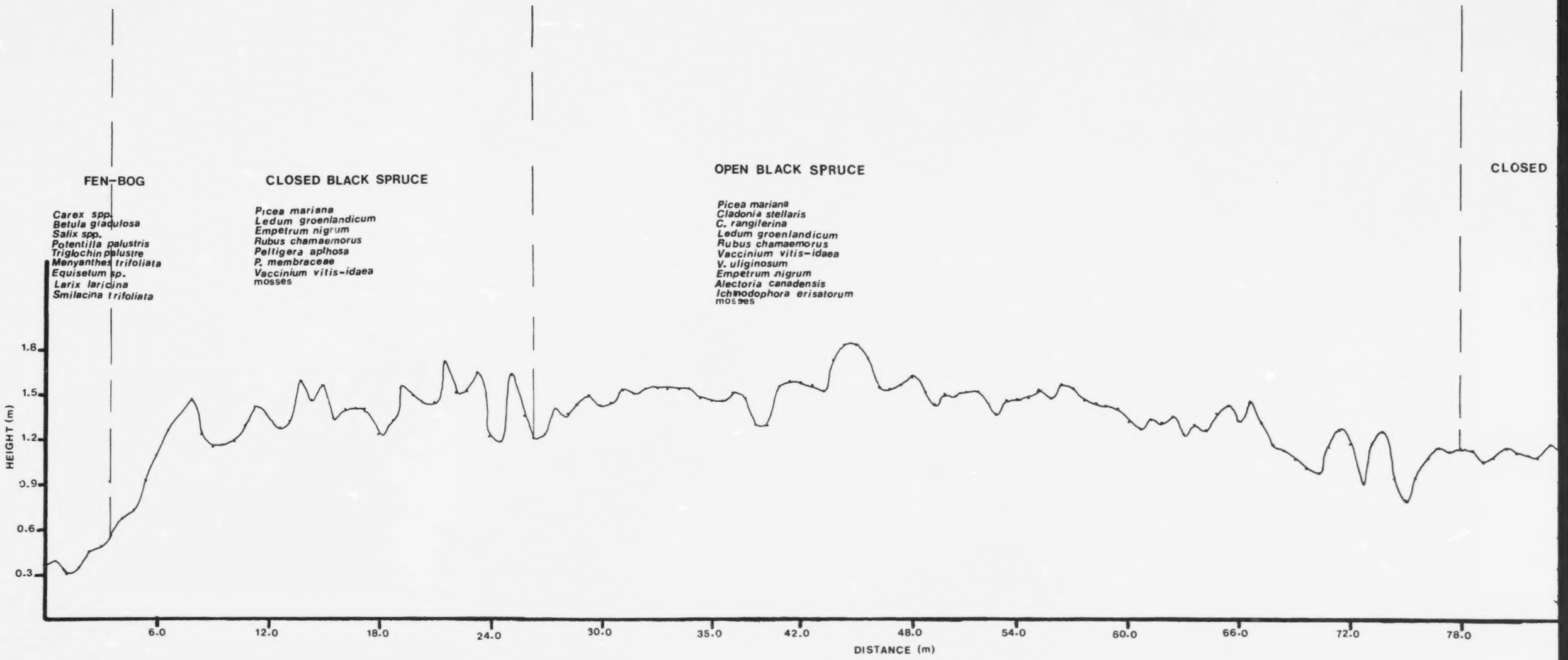
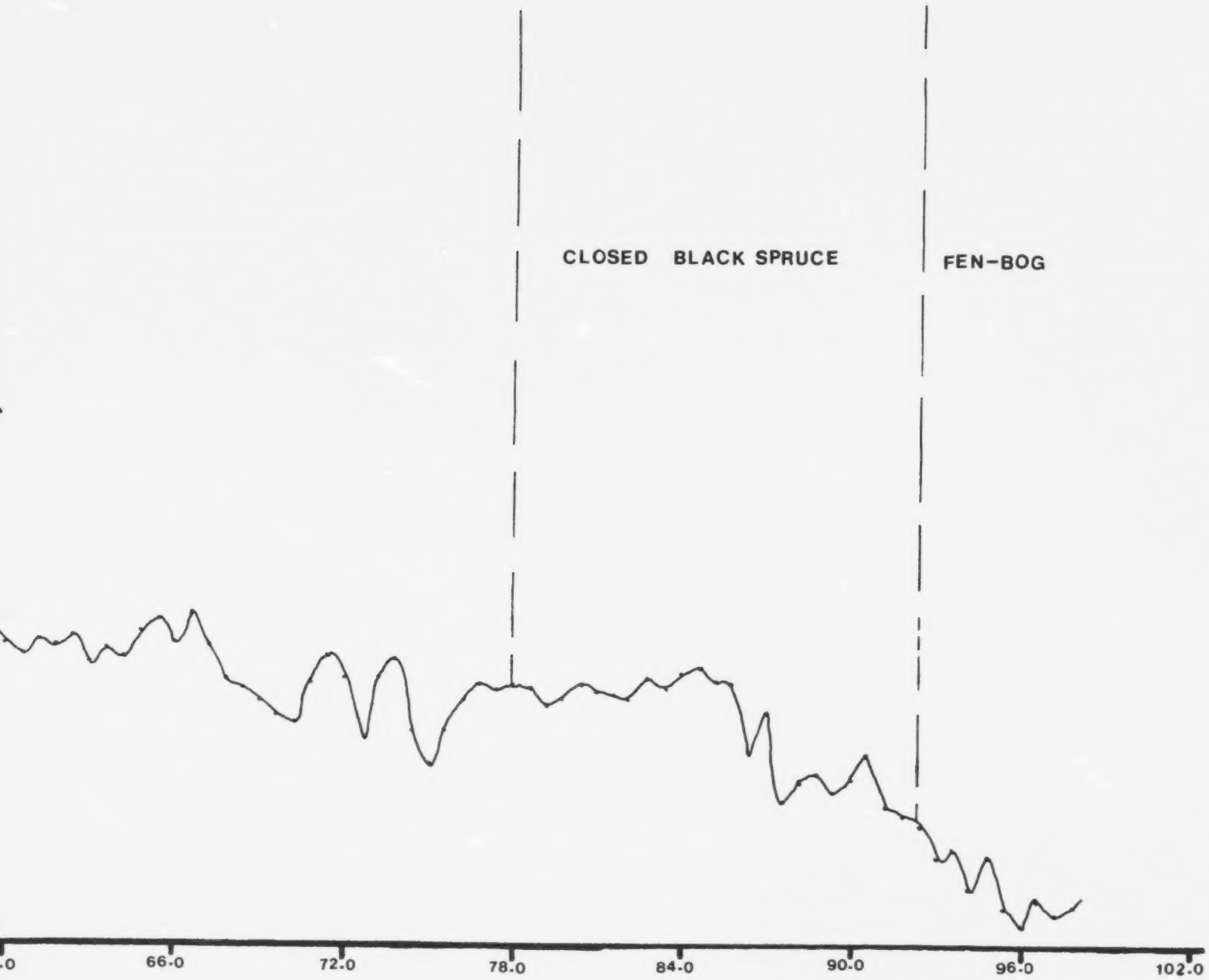


Figure 16: Cross-section of a peat plateau and distribution of associated plant communities.


CLOSED BLACK SPRUCE
FEN-BOG
66.0
72.0
78.0
84.0
90.0
96.0
102.0

resulting community resembles a spruce-lichen woodland occurring over sandy-silty ridges.

The ice lense is maintained within the peat layer by the insulation provided by the dry peat above and saturated peat below. Water is drawn horizontally, by capillary action from the fen to the freezing centre (Washburn 1980) aggrading ice. Subsequent freeze and refreeze cycles enlarge the pore size, the plateau and ice lense thus grow until a change in heat balance initiates degradation (Zoltai 1972).

An "overmature" plateau is high (1 m or greater) with thermokarst features and collapsing edges (Zoltai 1972). This action is initiated when the surface become excessively dry; cracking occurs and the ice lense is exposed or warm surface water runs through the cracks and melts the lense. The removal of insulative vegetation and peat has the same effect. Kershaw (1977) suggests fire is important in maintaining the spruce-lichen association on the peat plateau but burning could not occur without melting the ice lense, thereby destroying the structure. Fire then is important in rejuvenating an area by releasing the moisture and nutrient accumulations to allow the formation of new peat plateaux and other communities.

Brown (1977) believes palsas and peat plateaux are equivalent, the plateau being formed when palsas coalesce. Lundqvist (1969) believes they may be derived from special cases of hummocks where the ice forms in the peat layer. This is more likely the general case because permafrost under palsas are anchored to the mineral soil while peat plateau are not. Height of palsas result from the underlying permafrost while plateau height is the result of organic accumulation. Palsas often reach great heights, up to 7 or 9 m (Lundqvist 1969) while peat plateaux are rarely higher than 1-5 m (Zoltai 1972). The shape of the two is different -- palsas are mounds with gradual inclines and

and plateaux have steep edges. Trees are involved in the initiation of plateaux but are an intermediary of the palsas. These two structures should probably therefore be considered as separate entities with separate formation processes. Peat plateaux are unique structures whose underlying properties are yet undiscovered.

The plateaux are used by caribou in winter for the lichen food source and for cover.

CONCLUSION

The present study only touched the surface of information on the development of vegetation communities in the forest-tundra at Churchill, Manitoba. There appears to be more community types and variations within these types than are immediately distinguishable upon first observation. More research should be undertaken to discover the implicit formation processes of the periglacial structures and associated plant communities. The greatest limiting factor for such studies is time. The short growing seasons in this area require a great number of years to distinguish changes and trends compared to shorter periods of time in the south.

The forest-tundra is a fragile system very dependent upon permafrost as has been indicated. Degradation of the permafrost base will almost certainly be immediately detrimental. Disruption of the active or insulative layer should be carefully regulated if the ecosystem is to remain.

Bogs or wetlands are able to recover faster than upland areas because their cool, wet, anaerobic microclimate is conducive to peat deposition and re-establishment of the insulative cover. Beach ridges and periglacial structures on the other hand, are cool, dry and exposed to the aerobic environment. The regeneration of peat or insulation is very slow. Summer heat penetration is deeper, the active layer widens, permafrost melts and structural integrity is lost.

This process can very much be speeded up by constant traffic. Careful regulation must be considered to minimize the disruption of the insulative layer, perhaps restricting traffic to localized areas.

Another example of ecosystem disruption is fire. Fire is an integral part of boreal ecology in the north as it is in the south. Fire is necessary

to make nutrients available to the environment which would otherwise remain bound. Even though 250-300 years are required to re-establish the woodlands fire ensures a continuing availability of habitat and food for wildlife.

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APPENDIX I

Species List

PTERIDOPHYTA

Equisetum spp.

SPERMATOPHYTA

Potamogeton filiformis Pers.
Picea glauca (Moench) Voss
Picea mariana (Mill.) BSP
Larix laricina (DuRai) K. Koch
Juniperus communis L. var. *depressa* Pursh.
Triglochin maritima L.
Triglochin palustris L.
Festuca rubra L.
Festuca vivipara (L.) Sm.
Puccinella phryganodes (Trin.) Scribn. + Merrill
Hordeum jubatum L.
Elymus arenarius L. subsp. *mollis* (Trin.) Holt.
Calamagrostis neglecta (Ehrh.) Gaerth., Mey, Scherb.
Scirpus rufus (Huds.) Schrad.
Eleocharis palustris (L.) R & S
Eriophorum scheuchzeri Hoppe
Carex diandra Schrank
Carex glacialis Mack.
Carex capillaris L.
Carex rariflora (Wahl.) Sm.
Carex aquatilis Wahl.
Carex glareosa Wahl.
Carex rupestris All.
Carex saxatilis L. var. *millaris* (Michx.) Bailey
Carex scirpoidea Michx.
Carex magellanica Lam.
Carex subspathacea Wormskj.
Carex chordorrhiza L.f.
Juncus arcticus Willd.
Juncus balticus Willd. var. *littoralis* Engelm.
Salix reticulata L.
Myrica gale L.
Betula glandulosa Michx.
Populus balsamifera L.
Geocaulon lividum (Richards) Fern.
Rumex occidentalis S. Wats.
Salicornia rubra Nels.
Suaeda depressa (Pursh.) Wats.
Atriplex patula L.
Cerastium sp.
Melandrium sp.
Honkenya pepaloides (L.) Ehrh.
Ranunculus hyperboreus Rottb.

SPERMATOPHYTA (Cont'd.)

Saxifraga tricuspidata Rottb.
Parnassia multiseta (Ledeb.) Fern.
Potentilla egedii Wormskj. var. groenlandicum (Tratt.) Poulinin.
Dryas integrifolia Vahl.
Hedysarum mackenzii Richards
Oxytropis arctica R.Br.
Empetrum nigrum L.
Shepherdia canadensis (L.) Nutt.
Epilobium angustifolium (L.) Sweet
Hippuris vulgaris L.
Hippuris tetraphylla L.f.
Cicuta virosa L.
Ledum groenlandicum Oeder
Rhododendron lapponicum (L.) Wahl.
Loiseleuria procumbens (L) Desr.
Andromeda polifolia L.
Arctostaphylos rubra (Rehd. and Wils.) Fern.
Vaccinium uliginosum L.
Vaccinium vitis-idaea L.
Vaccinium myrtilloides Michx.
Menyanthes trifoliata L.
Linnaea borealis L. var. americana (Forbes) Rehd.
Utricularia intermedia Hayne
Arnica alpina (L.) Olin.
Senecio congestus (R. Br.) DC.

(Scientific names taken from Porsild (1955), Scoggan (1957) and Hulten (1968).

BRYOPHYTA

Tomenthypnum nitens (Hedw.) Loesk.
Campylium stellatum (Hedw.) L. & Jens.
Drepanocladus revolvens (C. M.) Warnst.
Hylocomium spp.
Dicranum spp.
Hypnum spp.
Sphagnum warnstofii Russow
Sphagnum fuscum (Schimp.) Klinggr.
Scorpidium scorpioides (Hedw.) Limpr.

(Scientific names taken from Conard (1956), Flowers (1973)).

LICHENS

Peltigera apthosa (L.) Willd.
Peltigera spp.
Caloplaca elegans (Link.) T. Fr.
Rinodina oreina (Ach.) Mass.
Alectoria nitidula (T. Sr.) Vainio
Alectoria ochroleuca (Hoffm.) Mass.

LICHENS

Parmelia disjuncta Erichs.
Parmelia sulcata Tayl.
Parmelia centrifuga (L.) Hale
Umbilicaria arctica
Cetraria islandica (L.) Ach.
Cetraria nivalis (L.) Ach.
Cladonia stellaris (Opiz.) Brodo
Cladonia rangiferina (L.) Harm.
Cladonia unicaulis (L.) Wigg.
Cladonia cornuta (L.) Hoffm.

(Scientific names taken from Thomsen (1953-1972) and Hale (1979).

APPENDIX II

HEIGHT PROFILES

Table A. Height measurements along profile of the Rock-Lichen Community.

Distance (m)	Height (m)	Distance (m)	Height (m)	Distance (m)	Height (m)
0	0	19.2	7.19	38.4	10.04
.6	.33	19.8	7.86	39.0	10.10
1.2	.75	20.4	7.69	39.6	9.96
1.8	1.45	21.0	7.90	40.2	10.04
2.4	1.21	21.6	7.75	40.8	10.16
3.0	1.69	22.2	7.80	41.4	10.22
3.6	1.96	22.8	7.78	42.0	10.24
4.2	2.07	23.4	7.72	42.6	10.29
4.8	2.24	24.0	8.05	43.2	10.36
5.4	2.56	24.6	8.02	43.8	10.38
6.0	2.86	25.2	8.53	44.4	10.46
6.6	3.07	25.8	8.79	45.0	10.95
7.2	3.68	26.4	8.70	45.6	11.49
7.8	4.16	27.0	8.77	46.2	11.93
8.4	4.58	27.6	8.70	46.8	12.85
9.0	4.87	28.2	8.91	47.4	12.14
9.6	5.20	28.8	8.80	48.0	12.26
10.2	5.45	29.4	8.73	48.6	12.40
10.8	5.46	30.0	9.23	49.2	12.33
11.4	5.57	30.6	9.35	49.8	12.57
12.0	5.49	31.2	9.03	50.4	12.61
12.6	5.42	31.8	8.77	51.0	12.92
13.2	5.39	32.4	7.76	51.6	13.10
13.8	5.37	33.0	7.74	52.2	13.34
14.4	5.86	33.6	7.77	52.8	13.56
15.0	5.88	34.2	7.04	53.4	13.43
15.6	5.90	34.8	7.97	54.0	13.41
16.2	6.04	35.4	8.39	54.6	13.57
16.8	6.50	36.0	8.62	55.2	13.64
17.4	6.77	36.6	9.40	55.8	13.86
18.0	6.75	37.2	9.23	56.4	13.85
18.6	6.70	37.8	9.51	57.0	13.56
				57.6	13.86
				58.2	13.92
				58.8	13.98

Table B. Height measurements along a profile of a palsa.

Distance (m)	Height (m)	Distance (m)	Height (m)	Distance (m)	Height (m)
0	.14	17.1	1.03	33.3	.65
.9	.08	18.0	1.20	34.2	.71
1.8	.05	18.9	1.15	35.1	.65
2.7	.09	29.8	1.35	36.0	.69
3.6	.04	20.7	1.15	36.9	.60
4.5	.06	21.6	1.23	37.8	.32
5.4	.17	22.5	1.16	38.7	.33
6.3	.23	23.4	- (tree)	39.6	.36
7.2	.28	24.3	1.16	40.5	.39
8.4	.34	25.2	1.12	41.4	.47
9.0	.45	26.1	1.03	42.3	.17
9.9	.59	27.0	1.00	43.2	.11
10.8	.61	27.9	.91	44.1	.21
11.7	.64	28.8	1.20	45.0	.06
12.6	.65	29.7	.87	45.9	.06
13.5	.70	30.6	.90	46.8	.10
14.4	.76	31.5	.84		
15.3	.90	32.4	.69		
16.2	.99				

Table C. Height measurements along a profile of a peat plateau.

Distance (m)	Height (m)		Distance (m)	Height (m)		Distance (m)	Height (m)
0	.35		23.4	1.67		46.8	1.65
.6	.38		24.0	1.23		47.4	1.53
1.2	.33		24.6	1.21		48.0	1.75
1.8	.37		25.2	1.37	Closed	48.6	1.52
2.4	.48		25.8	1.37	Black	49.2	1.50
3.0	.50		26.4	1.22	Spruce	49.8	1.56
3.6	.57	Fen-Bog	27.0	1.27	Open	50.4	1.54
4.2	.69	Closed	27.6	1.43	Spruce-	51.0	1.38
4.8	.75	Black	28.2	1.39	Lichen	51.6	1.45
5.4	.96	Spruce	28.8	1.46		52.2	1.47
6.0	1.12		29.4	1.49		52.8	1.47
6.6	1.29		30.0	1.44		53.4	1.56
7.2	1.34		30.6	1.44		54.0	1.48
7.8	1.50		31.2	1.57		54.6	1.59
8.4	1.25		31.8	1.54		55.2	1.56
9.0	1.17		32.4	1.57		55.8	1.47
9.6	1.16		33.0	1.58		56.4	1.43
10.2	1.21		33.6	1.56		57.0	1.42
10.8	1.31		34.2	1.57		57.6	1.41
11.4	1.44		34.8	1.57		58.2	1.35
12.0	1.42		35.4	1.51		58.8	1.30
12.6	1.31		36.0	1.48		59.4	1.36
13.2	1.34		36.6	1.48		60.0	1.33
13.8	1.64		37.2	1.54		60.6	1.37
14.4	1.43		37.8	1.48		61.2	1.26
15.0	1.60		38.4	1.31		61.8	1.33
15.6	1.37		39.0	1.31		62.4	1.30
16.2	1.43		39.6	1.57		63.0	1.39
16.8	1.42		40.2	1.64		63.6	1.43
17.4	1.41		40.8	1.64		64.2	1.35
18.0	1.25		41.4	1.62		64.8	1.44
18.6	1.34		42.0	1.54		65.4	1.33
19.2	1.56		42.6	1.74		66.0	1.18
19.8	1.53		43.2	1.84		66.6	1.12
20.4	1.48		43.8	1.85		67.2	1.08
21.0	1.46		44.4	1.74		67.8	1.01
21.6	1.75		45.0	1.57		68.4	1.00
22.2	1.53		45.6	1.55		69.0	1.15
22.8	1.54		46.2	1.61		69.6	1.31

Distance (m)	Height (m)	
70.2	1.19	
70.8	.94	
71.6	1.20	
72.0	1.10	
72.6	.95	
73.2	.79	
73.8	.96	
74.4	1.07	
75.0	1.12	Open
75.6	1.10	Spruce-
76.2	1.15	Lichen
76.8	1.14	Closed
77.4	1.05	Black
78.0	1.08	Spruce
78.6	1.13	
79.2	1.12	
79.8	1.09	
80.4	1.08	
81.0	1.15	
81.6	1.14	
82.2	1.22	
82.8	1.22	
83.4	1.77	
84.0	1.18	
84.6	.85	
85.2	1.05	
85.8	.66	
86.4	.73	
87.0	.76	
87.6	.68	
88.2	.72	
88.8	.84	
89.4	.62	
90.0	.57	Closed
90.6	.55	Black
91.2	.39	Spruce
91.8	.43	Fen-Bog
92.4	.26	
93.0	.41	
93.6	.15	
94.2	.11	
94.8	.20	
95.4	.15	
96.0	.16	

APPENDIX III

PLOT DATE SUMMARY

ROCK-LICHEN COMMUNITY

Table A. Local frequency of species along a sampled transect of the rock-lichen community.

| DISTANCE (m) | 0 | .6 | 1.2 | 1.8 | 2.4 | 3.0 | 3.6 | 4.2 | 4.8 | 5.4 | 6.0 | 6.6 | 7.2 | 7.8 | 8.4 | 9.0 | 9.6 | 10.2 | 10.8 | 11.4 | 12.0 | 12.6 | 13.2 | 13.8 | 14.4 | 15.0 | 15.6 | 16.2 | 16.8 | 17.4 | 18.0 | 18.6 | 19.2 | 19.8 | 20.4 | 21.0 | 43.2 | 43.8 | 44.4 | 45.0 | 45.6 | 46.2 | 46.8 | 47.4 | 48.0 | 48.6 | 49.2 | 49.8 | 50.4 | 51.0 | 51.6 | 52.2 | 52.8 | 53.4 | 54.0 | 54.6 | 55.2 | 55.8 | 56.4 | 57.0 | 57.6 | 58.2 | 58.8 | 59.4 | 60.0 |
|---|---|---